A

THESIS

entitled

"GEOCHEMICAL PROSPECTING STUDIES FOR BERYLLIUM IN CENTRAL AND EAST AFRICA"

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by

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ABSTRACT

The dispersion of beryllium from beryl-bearing pegmatites in Southern Rhodesia and Uganda was studied with the aid of a rapid colorimetric field test utilizing berillon II.

Two variations of the analytical procedure, a titration and a buffer method, were used, both capable of determining Be in the range 0.5-600p.p.m.with a productivity of 40-60 samples per man day. These methods were applied to the estimation of Be in rocks, minerals, soils, vegetation, stream sediments and waters.

Given suitable topographic and host-rock environments, anomalous Be values in the coarse fractions of soils were detected for distances up to 900 feet away from the mineralisation. Anomalous values were also detected in stream sediments for many thousands of feet downstream from the bedrock source.

In the vicinity of the pegmatites examined, anomalous amounts of Be in the coarser size-fractions of soils and stream sediments are considered to be due to beryl fragments, the distribution of which is dominantly governed by the mechanical dispersion of resistant beryl grains during the course of weathering and erosion. The Be content of the clay fraction, however, may be derived by the weathering of less stable rock-forming minerals.

In the study areas Be apparently is not concentrated in vegetation, organic carbon, clay or chemical precipitates. The mobility of the minor amounts of the metal released from weathered felspars and other rock forming minerals is probably controlled essentially by the pH of the environment.

Practical applications of the results are considered in relation to the problems of mineral exploration for beryl-pegmatites under the conditions prevailing in the study areas.

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APPENDIX II (PUBLICATIONS)

Publications in pocket of back cover.

A. DEBNAM, A. H., and WEBB, J. S., 1960. Some geochemical anomalies in soil and stream sediment related to beryl pegmatites in Rhodesia and Uganda. Trans. Instn. Min. Metall., Lond., 69, 1959-60 (Bull. Instn Min. Metall., Lond., No. 641, April, 1960). 329-344

B. Discussions and Contributions for A. Trans. Instn. Min. Metall., Lond., 69, 1959-60 (Bull. Instn Min. Metall., Lond., No. 645, August, 1960). 637-660.

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I INTRODUCTION

Recent advances in technology have brought to light many possible new uses for the minor metal beryllium, the main use of which had previously been in the preparation of alloys. For instance the metal may eventually have important applications in atomic reactor technology. Furthermore Be is being considered as a structural material for supersonic aircraft due to its light weight and strength at high temperatures (Martin, 1960). High cost of the metal and limited known natural resources, of which the mineral beryl is the only present source, may limit the widespread use of Be in the immediate future.

The average abundance, or clarke, of beryllium in the earth's crust has been estimated to be within the range 1.7-10 p.p.m. (parts per million), and the figure 4.2 p.p.m. given by Vinogradov (1956) may be a fair average. Although the greater part of the metal is dispersed as a trace constituent in common rock-forming minerals there is a tendency for Be to concentrate in the final phases of crystallisation of magmas, particularly in acid and intermediate pegmatites. The average clarke of Be in all pegmatites is about 20 p.p.m., and in beryl-bearing pegmatites it is approximately 200 p.p.m. (Beus and Fedorchuk, 1955).

The main Be mineral in pegmatites is beryl and although other Be minerals occur they are at present commercially unimportant.

The beryl is normally concentrated within particular zones of the pegmatite body, and if the concentration is sufficiently great and the mineral is coarse enough to permit hand-sorting, the deposit can often be profitably mined. Mechanical processes have been devised for concentration of fine-grained beryl which cannot be hand-sorted, but they have not been entirely successful.

In the event of a rapid increase in the demand for Be in the future, much larger resources of beryl will clearly be needed to supplement those already known.

Although euhedral beryl crystals can be recognised readily, the massive variety may resemble quartz, felspar or some of the lithium minerals. The tests for Be or for beryl, previously described, are not entirely satisfactory for field use. Perry and Cooke (1946) applied spectroscopy to the identification of minerals whilst prospecting for beryl. Geochemical and biogeochemical methods have been used in Russia to locate Be anomalies related to beryl pegmatites, also with the aid of spectrography (Zalashkova et al., 1958, and Karaeva et al., 1958). An instrumental method for the determination of Be, in which neutrons emitted by the element when it is activated by gamma-rays are counted, was developed by Brownell (1959). Many colorimetric and fluorimetric methods have been devised for the identification of Be in rocks, minerals and soils (McVay, 1960, and Dressel et al., 1960) but the tests lack sensitivity and are not directly applicable to large-scale geochemical prospecting surveys.

The present problem arose when the U.K. Atomic Energy Authority invited the Geochemical Prospecting Research Centre at Imperial College to undertake a study of the application of geochemical methods to the search for beryllium ores, particularly in beryl pegmatite areas in Rhodesia and Uganda. The project formed part of a co-ordinated programme which included research and development work on geochemical and instrumental (gamma-neutron beryllium monitor) techniques undertaken by the National Chemical Laboratory, the Atomic Energy Research Establishment at Harwell and the Atomic Energy Division of the Geological Survey of Great Britain.

In January, 1959, Dr. J. S. Webb, with the assistance of members of the staff of the United Kingdom Atomic Energy Authority, carried out preliminary sampling in the vicinity of a number of pegmatite occurrences in Rhodesia. The samples were returned to London where they were analysed spectrographically. The results have been described by Webb and Debnam (1959), and Kerbyson and Webb (1959). Anomalies with peak values of 10-80 p.p.m. Be were detected in the -190 micron fraction* of samples of residual overburden derived from beryl pegmatites of marginal or economic grade. No anomalies were obtained over sub-economic dykes. In some areas there was evidence of anomalous values in the local drainage but they could not be evaluated due to possible contamination. For both soils and stream sediments, background values ranged from

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*For details of fractions see Table 46, Appendix I p.190.

less than 3 p.p.m. Be in material derived from schist, to 6-10 p.p.m. in material derived from granite.

The investigations described in this thesis were carried out during a nine-month visit to Africa, from April to December, 1959. The analytical procedures are discussed in Section II. The results obtained from detailed studies in selected areas in Southern Rhodesia and Uganda, where different geological, topographic and climatic conditions prevail, are presented in Section III. Each area is considered separately and particular emphasis is given to the distribution of Be in soils and stream sediments. In Section IV there is a detailed discussion on the probable reasons for the types of Be distribution observed. Following a summary of conclusions in Section V provisional prospecting procedures for locating Be mineralization are given together with recommendations for further research. Sampling and analytical techniques employed during the work are detailed in Appendix I. Previous publications which deal with the project are given in Appendix II.

Acknowledgments

The study formed part of the overall research programme of the Geochemical Prospecting Research Centre, Imperial College, directed by Dr. J. S. Webb under the aegis of Professor David Williams. The Centre receives a substantial grant from the Department of Scientific and Industrial Research.

The writer is indebted to the United Kingdom Atomic Energy Authority which contributed towards the cost of the project and provided a bursary for the term of the study. In particular he wishes to thank Mr. C. Campbell of the London office, Mr. K. C. Branscombe of the Salisbury office, and the staff in Rhodesia and Uganda for their helpful advice and assistance extended to him personally. The use of laboratory space in Salisbury, the allocation of African assistants and the provision of geological maps and camping equipment, is greatly appreciated.

A Landrover and a quantity of chemical equipment and chemicals were kindly made available by the Director of the Geological Survey of Northern Rhodesia.

The Chief Geologist of the Atomic Energy Division of the Geological Survey of Great Britain, Mr. H. S. U. Bowie, is thanked for permission to use the facilities available in the Division; in particular Dr. K. C. Burke carried out field surveys with the portable gamma-neutron equipment and Dr. M. J. Gallagher assayed many samples with the laboratory gamma-neutron instrument and identified rock and mineral samples.

The author is deeply grateful to Mr. R. A. Wells and Mr. E. C. Hunt of the National Chemical Laboratory for their help with the analytical method and for providing the berillon.

Invaluable assistance in the solution of analytical problems was also given by Mr. R. E. Stanton of the Geochemical Prospecting

Research Centre. Other members of the College staff who assisted were Mr. J. D. Kerbyson and Miss D. A. Poynter, who supplied the spectrographic results, Miss A. J. MacDonald who analysed 400 samples for Be and carried out spectrophotometric determinations and Mr. J. A. Gee who kindly undertook the duplication of diagrams.

Finally the writer wishes to express his deep appreciation of the advice and guidance given throughout by his supervisor, Dr. J. S. Webb, who organised the overall programme and carried out the preliminary field studies upon which the present work is based.

II THE DETERMINATION OF BERYLLIUM

1. GENERAL

The analytical chemistry of Be has been studied by Vinci (1953), Toribara and Sherman (1953), and Sandell (1944). These authors list the various reagents used for the determination of the metal and describe analytical procedures. In general, the methods for the estimation of micro-quantities of Be consist of sample attack and solution, followed by the complexing or removal of interfering ions, and a colorimetric or fluorimetric determination with a specific reagent.

In addition, spectrographic (Creitz, 1958), radiometric (Milner and Edwards, 1959) and chromatographic (Agrinier, 1958 and Feigl, 1958) methods of Be determination have been used.

2. COLORIMETRIC METHODS USING BERILLON II

Most of the procedures referred to above lack the sensitivity and/or selectivity required in a geochemical prospecting field method. A colorimetric reagent, found to be suitable for the present project by Hunt _et al._ (1960) was Berillon II* (berillon). This reagent was first prepared by Lukin and

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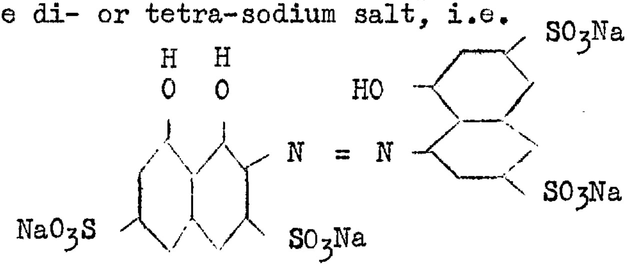
*Berillon II is: 8-hydroxynaphthalene-3, 6-disulphonic acid - (1-azo-2')-1'-8'-dihydroxynaphthalene-3'-6'-disulphonic acid as the di- or tetra-sodium salt, i.e.



Zavarikhina (1956), and its behaviour with Be with respect to colour changes with pH variations, interferences and sensitivity has been studied by Karanovich (1956) and Hunt et al. (1960).

The most important characteristic of berillon is the blue complex formed with Be at pH values of 11-13, which contrasts with the red-violet colour imparted to solutions of lower pH. Both the above authors use EDTA (ethylenediaminetetra-acetic acid) to suppress the interference of most metal ions, but whereas the former uses ascorbic acid to complex ferric iron the latter uses N,N-di (2-hydroxyethyl) glycine (or Nervanaid F).

The data obtained in the field and subsequently in London was obtained with provisional colorimetric procedures which included a titration method devised by the writer, and a buffer technique originated by R.E. Stanton, both of these tests being based on the analytical approach used by the National Chemical Laboratory chemists at a time when their field method was in an early stage of development. This latter method (N.C.L. Method) and the initial provisional buffer technique have been described by Hunt et al.(1960). Procedures for an improved provisional buffer method and the titration method are given in Appendices 1 and 2 of this thesis, respectively. All the techniques are discussed and compared below. The sample attack and leaching procedures are virtually the same for each method; the main variations occur in the approach to pH control.

A. Titration Method

The detailed procedure is given in the Addendum of Appendix 2, p.343-4.

In common with the other berillon methods, EDTA and Nervanaid F are used to complex all the interfering ions, so that the determination is specific for Be.

In this procedure the optimum pH for the maximum development of the blue berillon-Be complex is approached gradually by titrating the solution dropwise with 0.5N (2 per cent) NaOH. The colour change is from red-violet to violet or blue depending on the presence in the solution of small or large amounts (4 micrograms or more) of Be respectively. The maximum blue component of the colour, due to the berillon-Be complex, persists over the pH range of 11.5-12.2 during the addition of 4 drops (0.15 ml) of the 0.5N NaOH (Fig. 1).

The titration is possible due to the rapidity of development of the coloured complex at optimum pH conditions. It allows maximum colour sensitivity at the correct pH value and permits considerable latitude for errors in amounts of reagents added, due to the rigid control of the final conditions. Provided that the tubes in which the test is carried out are kept tightly stoppered, the colours will remain unaltered for up to at least three months.

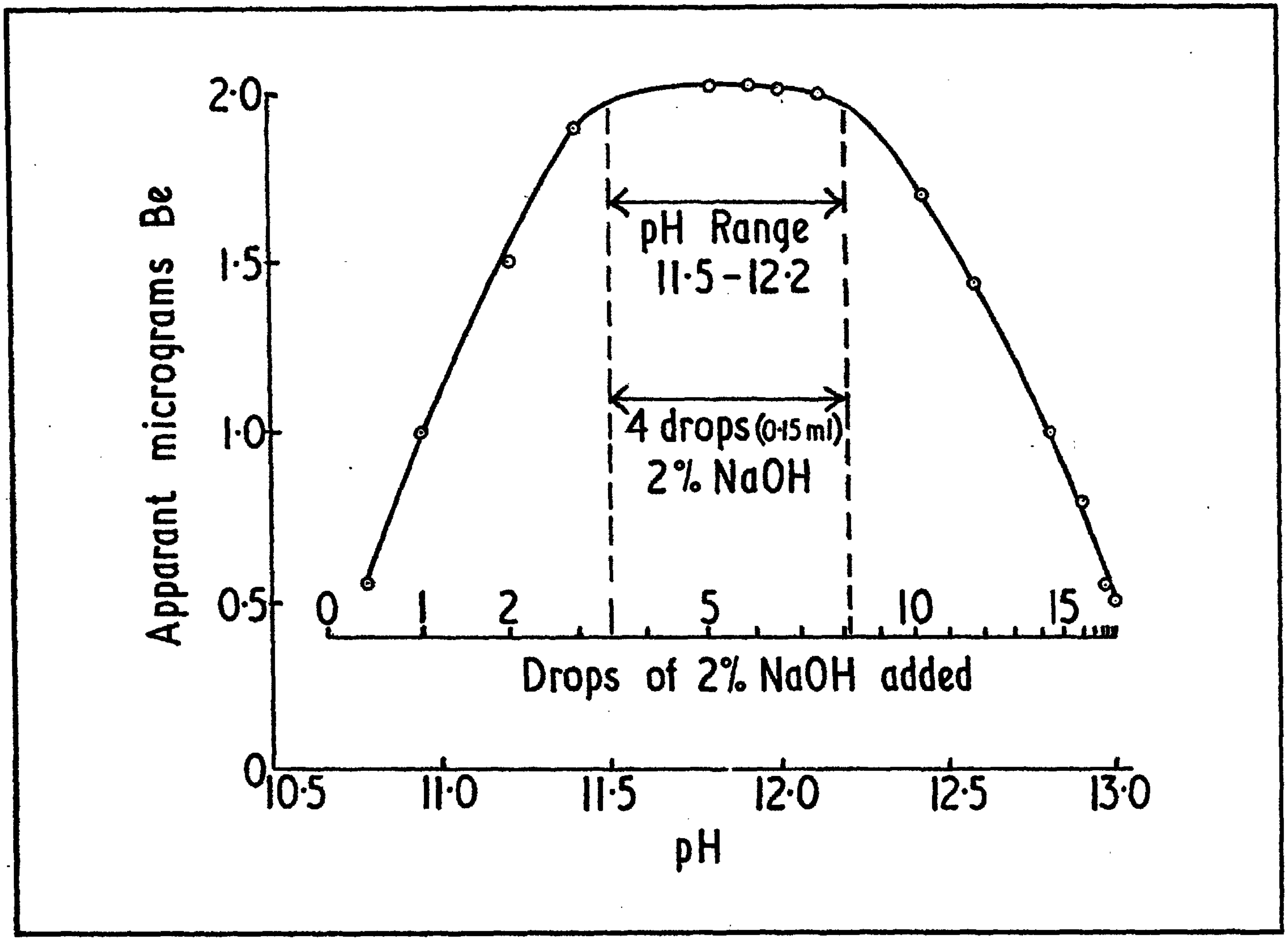


FIG. 1. VARIATION OF APPARENT Be WITH pH, TITRATION METHOD.

B. Improved Buffer Method

The original buffer method is not particularly tolerant to interference from ions such as ferric iron and chromium (Hunt et al. 1960). An improved buffer in which (a) the addition of Nervanaid F removed interference due to ferric iron, and (b) reduced concentration of tri-sodium orthophosphate prevented crystallization of this material on standing, was prepared by the writer and used for most of the Be determinations carried out in London subsequent to the field investigations.

In this method the pH of the final solution is buffered within the range 11.45-11.7, at which the blue component of the mixed colour, due to the berillon-Be complex, reaches maximum development (Fig. 2). Although this range is rather narrow it permits wide variations from the standard conditions owing to the buffering effect of the sodium phosphate. To compensate for the effect on pH of the 2ml of 0.2N HNO_3 test solution, to which 10ml of the buffer is added during the testing operation, it is necessary to prepare a buffer of pH 12.0; the final pH is then 11.55, approximately in the centre of the optimum range.

The relationship between the blue component of the mixed colour and the Be concentration is not linear (Fig. 3) and therefore does not follow Beer's Law over the range 0-4 mcg Be. The departure from a linear relationship may be due to the overlap of the absorption curves for the red-violet berillon reagent and the

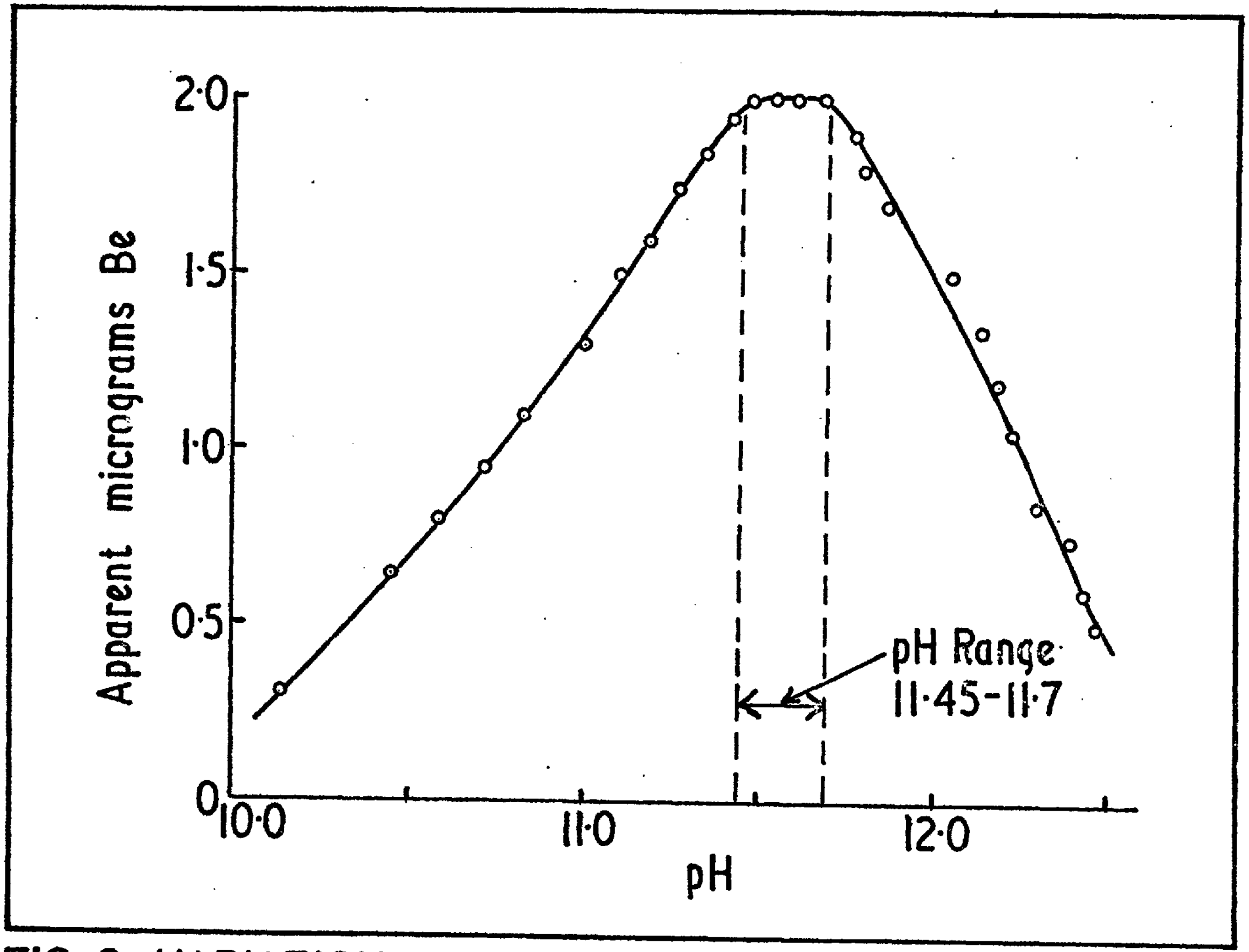


FIG. 2. VARIATION OF APPARENT Be WITH pH, BUFFER METHOD.

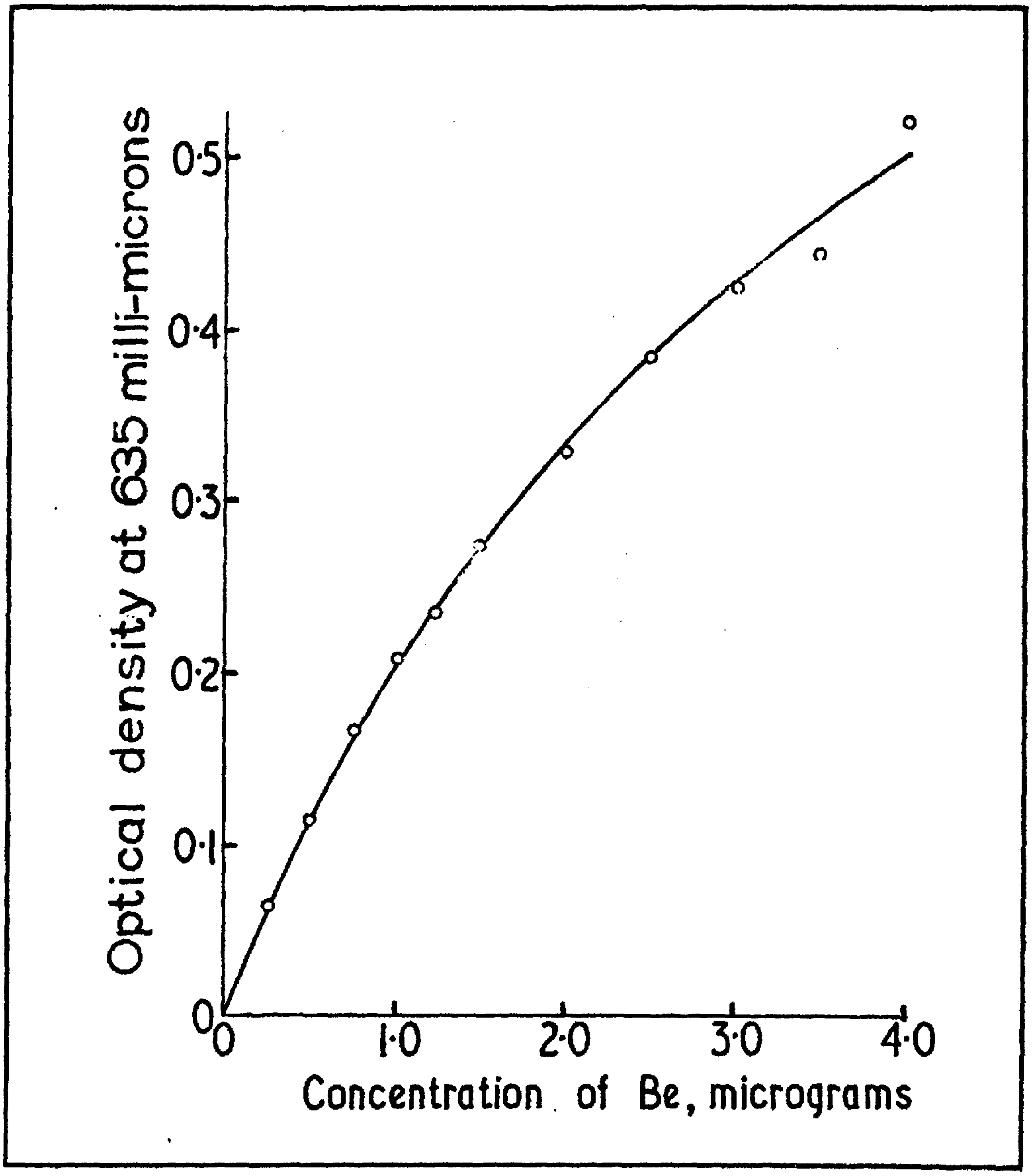


FIG. 3. RELATION BETWEEN COLOUR AND Be CONCENTRATION, BUFFER METHOD.

blue berillon-Be complex (Fig. 4). The greatest difference between optical density for the reagent and the complex occurs at a wavelength of 635 milli-microns, and this wavelength was used to obtain the curve in Fig. 3. The absorption data was determined by Miss A. J. MacDonald, with a Unicam SP600 spectrophotometer.

C. N.C.L. Method

In this procedure there is no attempt to control the pH rigidly, as in the other methods, but pH variations are minimised by carrying out the test at the high pH level of 12.5-12.6. Thus the method operates at a pH where the curves shown in Figs. 1 and 2 have a steep slope. This is a probable weakness, as only slight variations of pH will affect the amount of blue component of the mixed colour, producing erroneous Be values and a poorer accuracy. Maximum sensitivity is also sacrificed.

The writer has found that by increasing the berillon concentration to 0.02 per cent (from 0.005 per cent), it is possible to view the tubes transversely rather than along the vertical axis, as detailed by Hunt et al. (1960). This not only eliminates the necessity of removing stoppers from the tubes, but it also permits the standard solutions to remain stable for several weeks. There is no loss in sensitivity.

D. General Discussion of the Berillon Methods

In a comparison of the Be values produced by the three berillon methods (Table 1), the results given by the gamma-

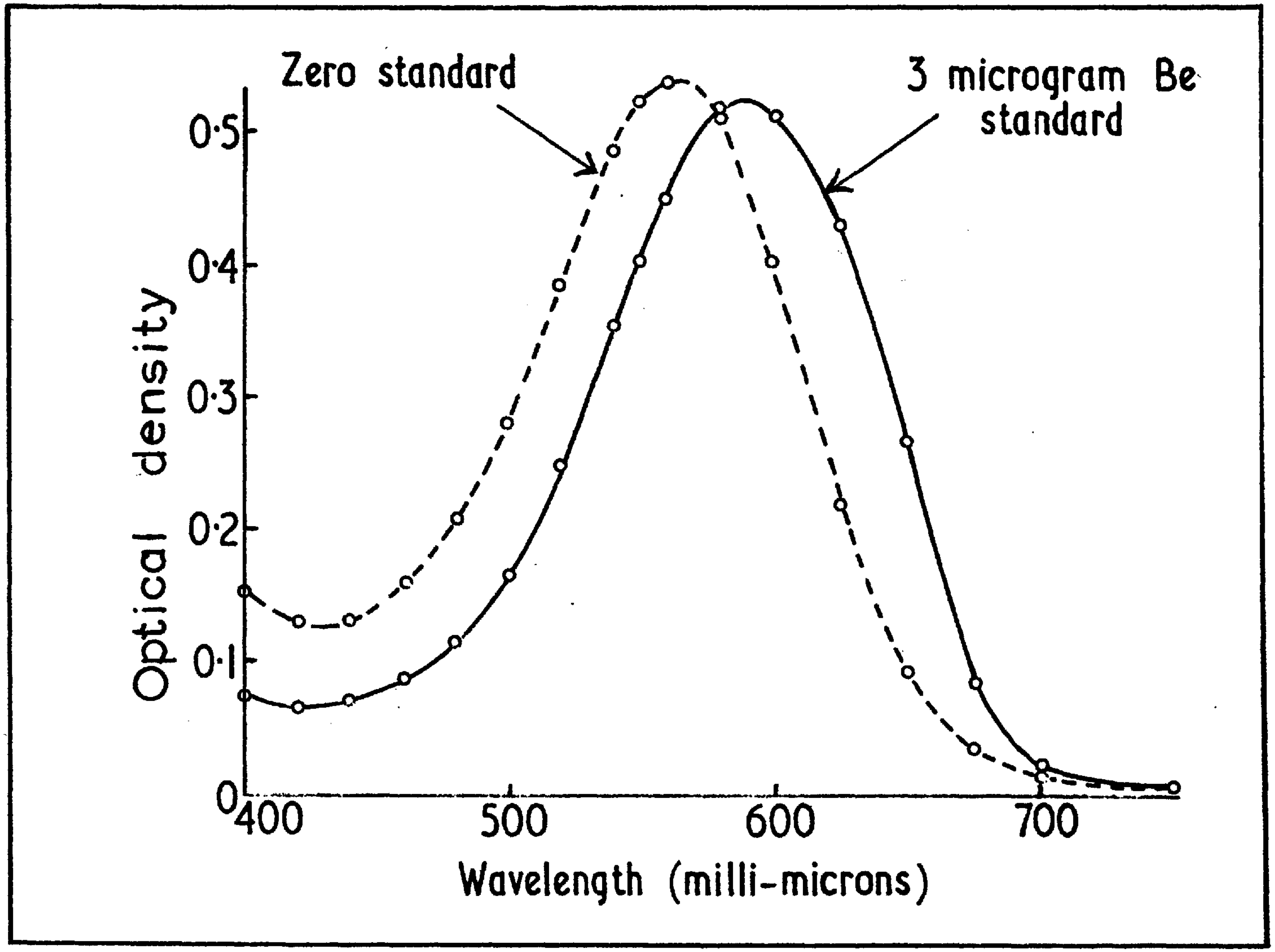


FIG. 4. ABSORPTION CURVES FOR BERILLON AND THE BERILLON-Be COMPLEX, BUFFER METHOD, pH 11.6.

neutron assay technique (Bowie et al. 1960) and by spectrochemical analysis (Kerbyson and Webb, 1959) are included. Despite evident

TABLE 1

Comparison of Be values obtained by various laboratory techniques

Sample No.	p.p.m. Be				
	Colorimetry			Gamma-neutron assay *	Spectrography†
	Titration	Buffer	N.C.L.		
6275	0.4	< 0.5	0.5	1	5
76	1	1	0.5	3	8
77	16	9	12	20	35
78	35	25	19	45	55
79	30	19	25	35	45
80	90	60	65	90	100
81	110	65	70	100	105
82	90	60	60	70	80
83	25	18	25	25	25
84	25	13	17	17	25
85	20	10	15	13	16
86	13	8	8	10	8

-190 micron fraction, dry-sieved and uncrushed

*Gamma neutron assays by U.K.A.E.A., Salisbury.
†Spectrographic analyses by J. D. Kerbyson.

bias, each method is capable of distinguishing between high and low values.

There is, however, a general tendency for the colorimetric figures, particularly those given by the buffer and N.C.L. methods, to be low in comparison with those of the other methods. This tendency is more emphasised when minerals, or the coarse fractions of soils, are analysed. The probable reasons for the low values are discussed below:-

1. Sample attack Incomplete sample attack, which could occur if coarse particles are present, or if some minerals are not susceptible to the treatment with fluoride e.g. pure quartz and perhaps albite, could result in low values. It has been shown by Hunt et al.(1960), that beryl in a finely dispersed state is completely attacked by the ammonium fluoride treatment.

2. Heating Insufficient heating at the end of the sample attack may not convert all the iron in the sample to the insoluble oxide, with the result that large amounts of ferric iron, which may not be complexed entirely by the Nervanaid F, may be dissolved by the acid leach.

3. Incomplete solution If a sample is completely attacked the residue may form a glassy melt which is difficult to leach. The effect is particularly noted when coarse-fractions and minerals are analysed. In some cases only 60 per cent of the true content may be determined in the first analysis (see sample no. 7646, Table 2).

TABLE 2

Effect of incomplete solution of the residue from ammonium fluoride attack (Buffer method)

Sample No.	Size-fraction (microns)	p.p.m. Be			
		1st Attack	1st Residue re-extracted	2nd Attack	3rd Attack
770	-190	10	1	2	
837	-190	13	3	3.5	
2497	-190	11		3	
5393	-190	100		24	
7619	2000-6350	42	3	3	
"	470-900	160	6	4	
"	2-20	370		26	
7623	-190	70		17	
7625	900-2000	54	1	1	
"	100-190	36	3	4	
7628-29	470-900	60	0.5	1.5	
"	20-80	130	2.5	4	
7646	-190	32		13	5
7649	-190	20		8	2.5
7687	-190	90	4	6	

4. **Precipitation** A precipitate sometimes forms in the final test solution, particularly when the original sample contains readily attacked felspars. Spectrographic analysis of the

precipitate (by Miss D. A. Poynter) indicates that the predominant metallic constituents are Al and Si, with minor Mg. They are probably in the form of hydroxides. The precipitates flocculate 10-15 minutes after the final test solutions have been mixed. Britton (1956) attributes this delay to the presence of nitrate in the solution, and the effect may be accentuated by the presence of EDTA.

Although the precipitates settle to the bottom of the tubes after flocculation and do not interfere with the colour comparisons, they may, however, co-precipitate or adsorb some of the Be present in the solution, resulting in low values. Errors due to this source may be minimised, or even eliminated, by testing small aliquots of test solution (Table 3) e.g. for sample no. 3393 a

TABLE 3

Effect of reduction in test-solution aliquot on Be value (Buffer method)

Sample No.	p.p.m. Be			
	Aliquot (ml)			
	2	1	0.5	0.2
179	32	40		
181	30	35	40	
182	27	34		
3389-92	17	20		
3393	25	30	30	
3394	28	40		
4665			100	95
4671	30	35	40	
5304		50	56	

strong precipitate was produced with a 2 ml aliquot; by reducing the aliquot to 1 ml much less precipitate was apparent, and with a 0.5 ml aliquot it was absent.

This effect of adsorption of Be on the precipitate is demonstrated also by adding 2 micrograms (mcg) Be to a sample extract and determining the Be in solution, using various aliquots:

	p.p.m Be	Loss, p.p.m Be
Original value	11	
Equivalent Be added	20	
Apparent content, 2 ml aliquot	26	5
" " 1 ml aliquot	30	1

In view of this effect, it is advisable to reduce sample aliquots if precipitates occur.

If two or more of the factors discussed above occur in a single determination, a rather low value may be expected from the colorimetric determination in relation to that which would be obtained by the gamma-neutron assay, or from spectrography.

However, the majority of determinations carried out in the present investigation dealt with the fine soil fractions, and the above factors were at a minimum. Thus the buffer method was adopted for general use, and the possibility that some values may be low must be borne in mind. This, however, is a failing of all the colorimetric procedures, and additional research is required to perfect these methods.

E. Performance of the Analytical Methods

The performances of the various analytical techniques are summarized in Table 4.

TABLE 4

Comparison of performances of various analytical methods for Be determination

Feature	Colorimetry			Gamma-neutron assay	Spectrography
	Titration	Buffer	N.C.L.		
Sensitivity (mcg)	0.05	0.05	0.05		
(p.p.m.)	0.1	0.5	0.5	3*	1
Range (p.p.m.)	0.1-600	0.5-600	05.-600	3-50,000	1-5,000
Precision[†] (per cent) (Mean reproducibility)	± 15	± 20	± 30	± 30	± 50
Productivity	40-50	50-60	50-60	8[‡]	25-35

*Gamma-neutron assays at very low levels require counting periods of at least 12 hours.

[†] Determined by the method of Craven (1954). In this method of calculating accuracies, a statistical series is prepared by mixing two samples, with high and low Be contents, in known proportions. The series is analysed by a particular procedure and the Be values obtained are used to calculate the standard deviation, from which the mean reproducibility is obtained. The accuracy is at the 95 per cent confidence level.

[‡] Productivity of the gamma-neutron instrument depends upon the tenor of the samples and the accuracy required; those containing 10-100 p.p.m. Be would need at least 1 hour per sample, given an acceptable precision. However, one man could operate more than one instrument simultaneously.

F. Rapid Field Test for Beryl

A rapid field test for the identification of beryl is desirable owing to the similarity of some varieties of beryl to quartz and felspar. Some attention has been given previously to this problem; varying success has been achieved by Anderson (1957) with heavy liquids, by Kulcsar (1943), Jedwab (1957), McVay (1960) and Dressel and Ritchey (1960) with colorimetry, and by Feigl (1958) with spot tests.

The writer has developed a method, using the berillon reagent, which gives a rapid and distinctive identification of beryl. Up to 20 mineral fragments (2-5 mm diameter) may be tested concurrently.

The mineral fragments are sintered with ammonium fluoride in a 25 ml silica crucible for 2 min, after which the heat is increased to drive off excess fluoride. If only one fragment is being tested the following additions are made directly to the fragment in the crucible: 5 drops of 0.2N HNO_3, 1 drop of 0.5 per cent berillon reagent (dissolved in water), and 2 per cent NaOH dropwise. If the mineral fragment is beryl a strong blue colour will develop in the solution after the addition of about 8-10 drops of NaOH. However, if the colour of the solution remains red-violet the fragment is not beryl. In the case where several fragments have been treated, they are placed on a filter paper at least 1 cm apart. Onto each fragment 2 drops of 0.2N HNO_3, 1 drop of 0.5 per cent berillon reagent and 2-3 drops of 2 per cent NaOH are placed consecutively, so that after each addition the liquid soaks into the filter paper. A strong blue coloration develops on the paper beneath a beryl fragment, whereas only dark red-violet colours appear beneath other minerals.

The method should apply to other Be minerals, provided that they are attacked by the ammonium fluoride.

III. THE OBSERVED DISTRIBUTION OF BERYLLIUM IN THE VICINITY OF BERYL PEGMATITES

During the course of the field investigations approximately 8,000 samples were collected, mainly of rocks, soils and stream sediments, together with a few vegetation and stream water samples. The locations of the study areas at the Bepe and Mistress claims in Southern Rhodesia, and at Ishasha in South West Uganda, are shown in Fig. 5.

Each of the three study areas and the results obtained therein are described under separate headings on the following pages.

1. BEPE AREA, SOUTHERN RHODESIA

A. Description

Physical features: The Bepe area is situated near the eastern border of Southern Rhodesia, at latitude 19°10'S and longitude 32°0'E (Fig. 6).

Although the area lies within the tropics the prevailing climate is sub-tropical with hot, wet summers and cool, dry winters. The summer mean daily maximum temperature is above 80°F and the mean minimum above 60°F. During the winter daily temperature may rise to 75°F or more, whereas the night temperature may approach freezing. The rainfall is distinctly seasonal with more than 80 per cent of the total mean precipitation of 25 inches occurring during the four months

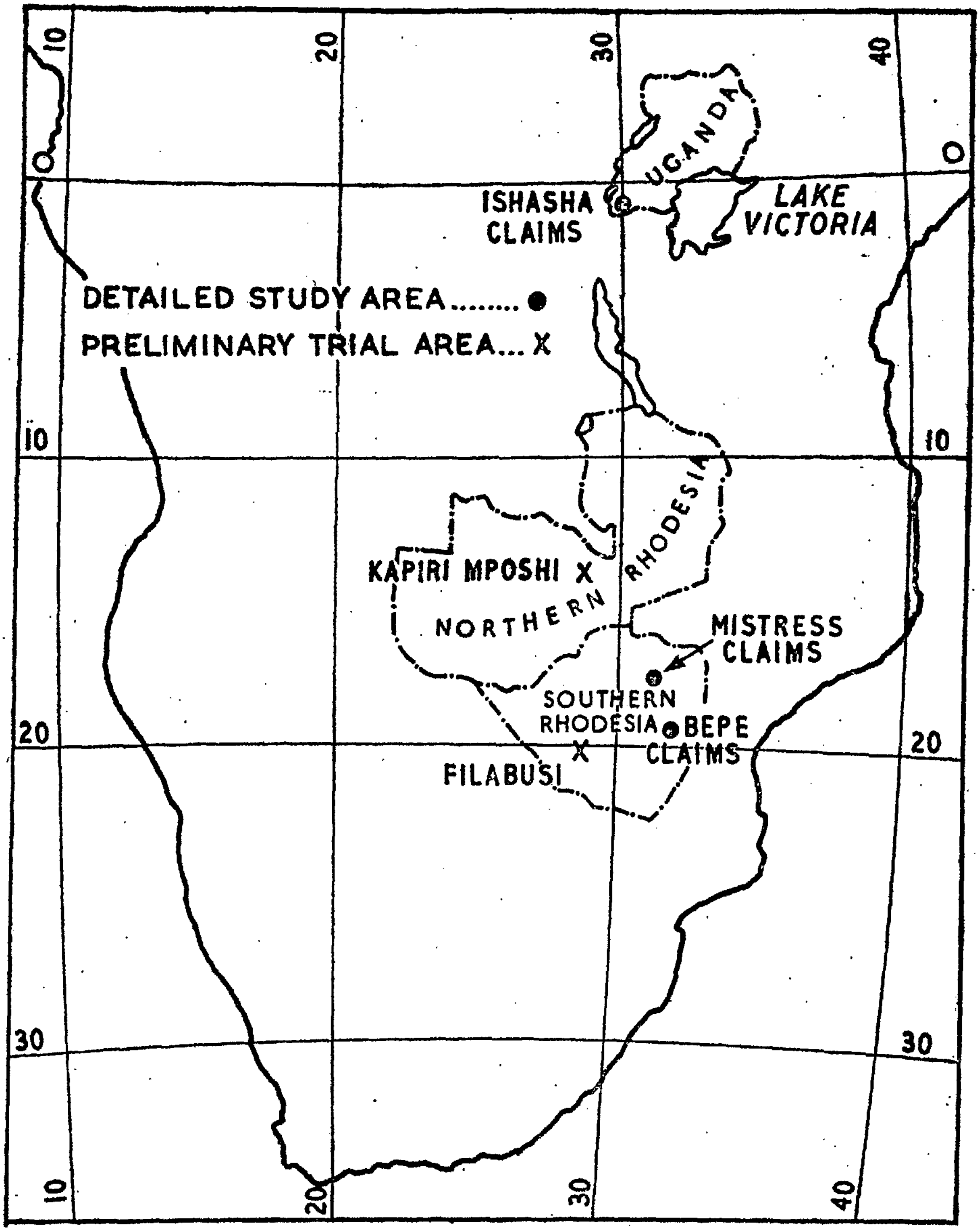


FIG. 5. LOCATION OF BERYL - PEGMATITE STUDY AREAS.

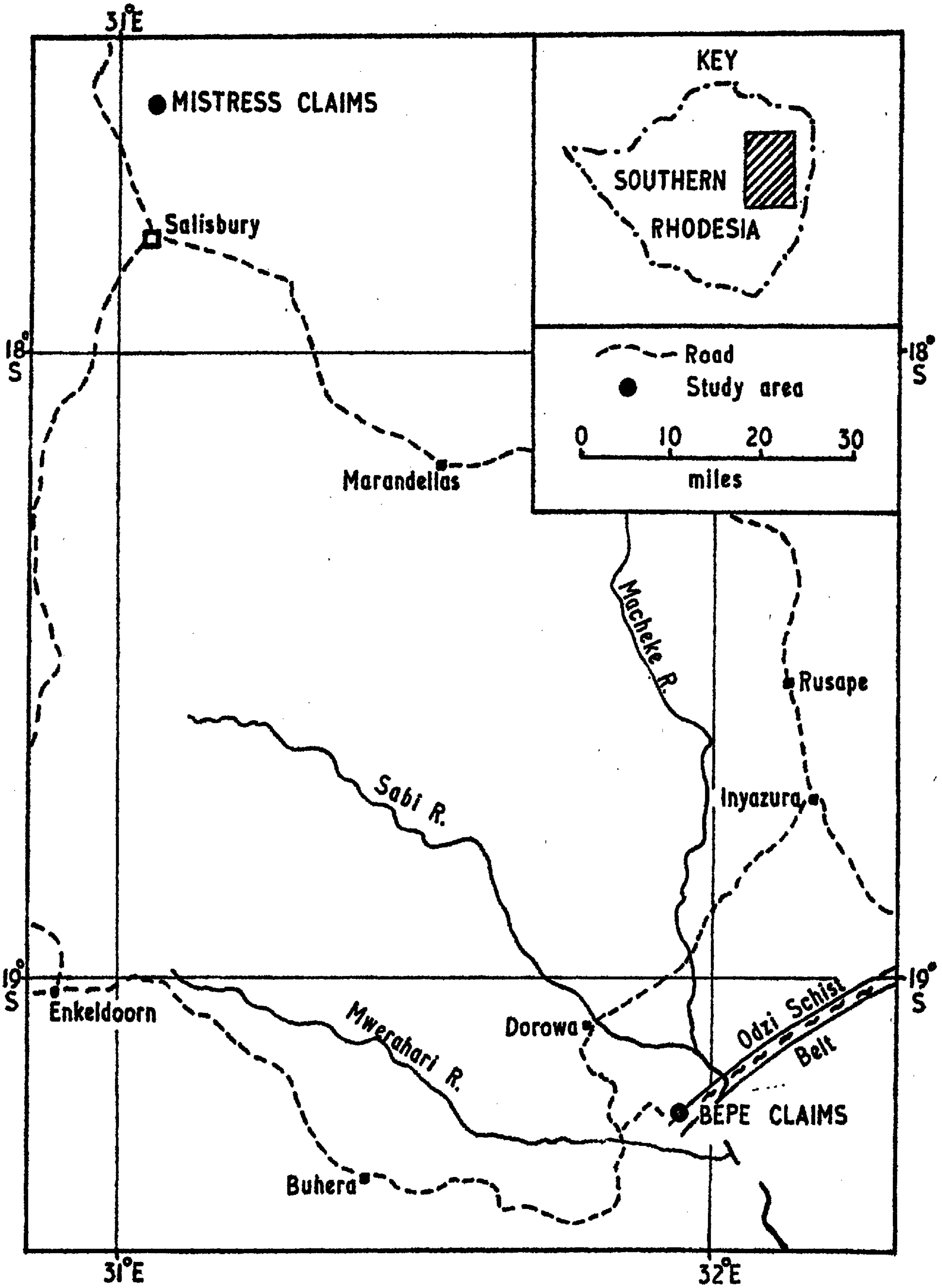


FIG. 6. LOCATION OF STUDY AREAS IN SOUTHERN RHODESIA.

November-February inclusive.

The predominant vegetation is thin sub-tropical deciduous forest; in places the trees, which do not exceed forty feet in height, have been cleared for cultivation. The two species selected for sampling were:

Terminalia sericea (common name: mususu)

and Brachystegia boehmii (common name: mupfuti)

The Bepe claims are situated at the foot of the northern slopes of the Bepe Hills which form the south-western end of the Mtanda Range, a series of hills extending for 30 miles to the north-east.

The generally predominantly flat terrain is 2,800-2,900 feet above sea-level, and above this level the Bepe Hills rise abruptly to heights of 500-700 feet. The pegmatites usually form minor topographical features rising to heights of up to 50 feet above the general level.

The Bepe Hills form the watershed between the Mukubu River to the north and the Mwerahari River to the south (Fig. 7) and thereby control the local drainage. Each of these rivers flows east into the Sabi River, but whereas the Mwerahari River flows strongly throughout the year the Mukubu River and all smaller streams are seasonal, flowing only during the wet season.

The main rock types in the eastern part of Southern Rhodesia belong to the Pre-Cambrian Basement Complex, consisting of granite, granite gneiss or basement schists. The latter rocks constitute the numerous "gold belts" of which the Odzi gold belt is an example. This belt is apparently more resistant to erosion than the surrounding granite and is the cause of the prominent Bepe Hills and Mtanda Range.

Geology: The geology of the Odzi gold belt has been described by Swift (1956). The general form of the belt appears to be that of a narrow syncline, the dips of the rocks being 70 to 85 degrees towards the central axis which probably originated during the emplacement of granite. The dominant rocks of the belt are ultrabasic in composition, namely serpentines, talc-, tremolite- and actinolite-schists, often intimately associated with numerous thin bands and lenses of banded ironstone. The sedimentary rocks include banded ironstones, impure quartzites, arkoses and limestones. The intrusion of granite into the above rocks was accompanied by metamorphism and mineralization. Both granites and schists are cut by aplites and granite-pegmatites. During a period subsequent to the metamorphism, bodies of dolerite were emplaced in both schists and granite, mostly as sills. The sedimentary rocks occur mainly on the tops of hills in the axis of the belt; the schistose rocks, which weather more readily than the massive rocks, occupy the low ground on the sides of the gold belt and the cols between the higher hills. The local geology of the Bepe area is presented in Fig. 7, which also

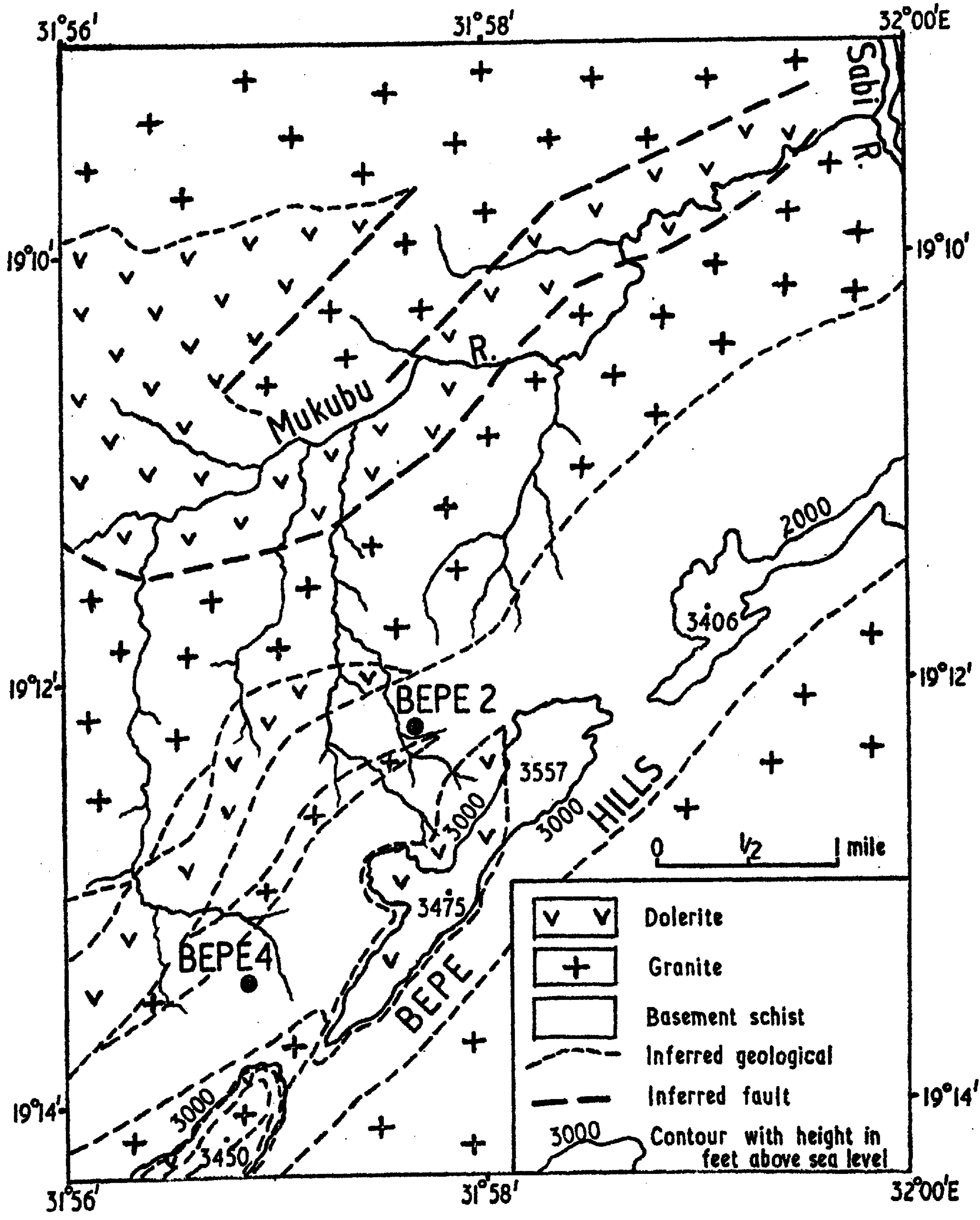


FIG.7. GEOLOGY AND TOPOGRAPHY OF THE BEPE AREA (after Swift, 1956).

gives the positions of the Bepe 2 and Bepe 4 pegmatites.

During the present investigations an intensive study was made of the primary and secondary dispersions of Be in and around the Bepe 2 pegmatite which has been intruded unconformably into tremolite schists (Figs. 8 and 10). This pegmatite conforms with the group of fully-differentiated muscovite-microcline pegmatites according to the paragenetic zonal classification of granitic beryl-bearing pegmatites drawn up by Beus (1956a). Pegmatites of this group exhibit normal development of a zone of medium- and coarse-grained pegmatite, predominant development of the zones of massive microcline and massive quartz, wide development of a muscovite replacement and weak development of an albite replacement complex.

In plan, the Bepe 2 dyke averages more than 200 feet in width, over a length of 350 feet. At the western extremity where it has been worked in the Lucky Bean open-cast the dyke thins to less than 100 feet in width. The shallow dip of 25° along the northern and eastern boundaries, and the almost vertical dip of the western boundary may indicate that erosion has only exposed the apical portion of the pegmatite body and that its thickness probably increases in depth.

The northern and eastern contacts with schist (dipping at 25°) are characterised by a 6-18 in. aplitic selvedge which is extremely hard and fine-grained and is composed chiefly of albite, spodumene, quartz and kaolin. This rock is also

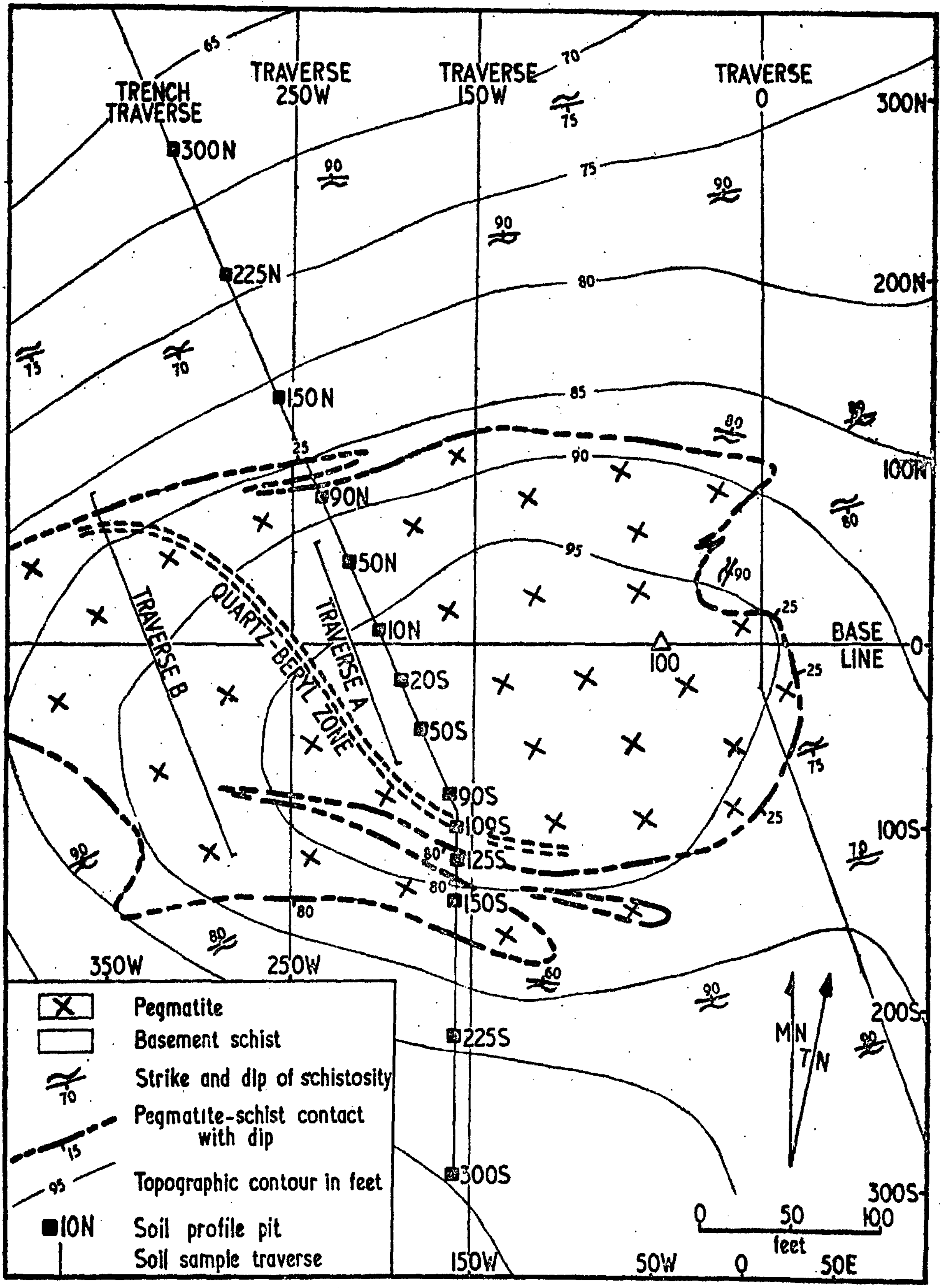


FIG. 8. GEOLOGY AND TOPOGRAPHY OF THE BEPE 2 PEGMATITE, WITH TRAVERSE LINES AND PROFILE POSITIONS.

present at the contacts with the schist wedge which divides the pegmatite off-shoot on the southern side of the dyke from the main pegmatite, but it is absent along the southern boundary of the off-shoot, indicating that this may be a faulted contact with the schist.

Enclosed by the marginal aplite (or directly in contact with schist if the aplite is absent) is the outer zone of the dyke, consisting of medium-grained quartz-felspar-mica pegmatite. On the northern side of the dyke this zone is 30 feet wide; on the southern side it is 50 feet in width. On either side schist inclusions or projections may occur within this zone. The pegmatite body is reasonably well differentiated and the outer zone has a sharp boundary with the inner zone composed of giant crystal-blocks of potassium felspar (microcline-perthite) with dispersed quartz blocks of small dimensions. This zone is 180 feet wide. The quartz core is only weakly developed, being less than 5 feet in width. Muscovite replacement zones occur in the south-western section of the dyke; there is noticeable albitization in sections of the potassium felspar inner zone and the medium-grained pegmatite outer zones. Some biotite and tourmaline is associated with the quartz core and a thin band of biotite-tourmaline schist is usually present at the pegmatite-schist contact.

The beryl is mainly concentrated as large crystals or crystal nests in the quartz core, but crystals also occur throughout the potassium felspar zone, particularly in close association with the quartz blocks. In addition there is an increased concentration of beryl in the outer zones of partly albitised medium-grained pegmatite and in the muscovite replacement complex. According to Beus (1956a) the chief characteristic of the fully-differentiated muscovite-microcline pegmatities is the coarsely-crystalline nature of the beryl which has a small alkali content. This type of beryl has well developed hexagonal crystals of long-prismatic habit, e.g. one crystal exposed at Bepe 2 was 14 inches in diameter and greater than 2 feet in length. Crystals are seldom less than one inch in diameter and two inches in length, a factor which facilitates benefication by hand-sorting. The occasional beryl crystals in the inner potassium-felspar zone are alkali-rich and may also be of large dimensions, but those in the albitised portions of the outer zones are relatively small though more uniformly distributed. Beus (1956a) considers that the beryl content of this type of pegmatite varies between 0.2 and 0.5 per cent, rarely exceeding the latter limit.

The Bepe 4 pegmatite belongs to the same group of the Beus classification as the Bepe 2 dyke, the beryl again being chiefly associated with the quartz core.

Overburden: With the exception of ridge crests and stream courses, the geology is generally concealed beneath a dominantly residual overburden ranging from 1 to 8 feet in thickness. In general terms, the type of bedrock determines the character of the overlying material in which changes in colour are commonly apparent on passing from one bedrock to another. Soils overlying granite and pegmatite show a slight tendency to differentiate into horizons but these are distinguishable only on the basis of colour and not on textural relationships. Schist soils, on the other hand, show very little profile differentiation.

In the absence of any visibly distinct B horizon, soil profiles are subdivided simply into a topsoil, often showing traces of organic matter or a fine texture, overlying a mineral subsoil which may differ in these respects and in colour from the topsoil.

Typical profiles of soils developed over pegmatite, schist and granite in the Bepe area are described below.

Soil Profile Developed over Pegmatite, Bepe 2
(10N in Trench Traverse)

Depth, ins.	Horizon	Colour and texture	pH
0-4	Topsoil	Grey-brown loam with some angular quartz fragments up to ½ in. in diameter.	6.8
4-10	"	Grey-brown loam with angular quartz fragments up to 1 in. in diameter.	
10-17	Subsoil	Grey-brown (at top) grading to brown (at bottom) sandy loam between angular quartz rubble up to 2 in. in diameter.	6.0

Depth, ins.	Horizon	Colour and texture	pH
17-26	Weathered bedrock,	mainly angular gravel ($\frac{1}{4}$-$\frac{1}{2}$ in.) of felspar with a little reddish-brown sandy loam between the fragments and some angular quartz fragments up to 1 in. in diameter.	
26+	Weathered bedrock,	soft brownish white weathered felspar.	

The grey-brown colour of the topsoil is quite distinct from the brown and red-brown colours of deeper horizons and it may be due to a combination of sesquioxide leaching and the influence of small amounts of organic material. The profile described is above the potassium felspar zone of the pegmatite and the numerous angular quartz fragments are probably derived from the quartz blocks which are present throughout this zone. Profiles over the outer zones of the pegmatite contain more mica and quartz in the lower horizons.

Soil Profile Developed over Schist, Bepe 2
(300N 200E)

Depth, ins.	Horizon	Colour and texture	pH
0-3	Topsoil	Dark-brown clay-loam, no fragments.	6.6
3-6	Subsoil	Dark-brown to brown clay loam, granular, with some weathered schist and banded-ironstone fragments.	

Depth, ins.	Horizon	Colour and texture	pH
6-11		Strongly weathered schist, mainly dark-brown mottled with black, yellow and green, quite soft.	
11-19		Weathered schist, mainly brown mottled black, brown and white.	

This profile differs from that previously described in that the topsoil is almost indistinguishable from the subsoil, there are no quartz fragments and there is a much higher percentage of clay-sized material. Organic material does not appear to contribute appreciably to the characteristics of the topsoil.

Soil Profile Developed over Granite, Bepe Area

Depth, ins.	Horizon	Colour and Texture
0-9	Topsoil	Grey-brown sand with fine quartz gravel.
9-18	Subsoil	Brown sand with fine quartz gravel and some soft white weathered felspar.
18-26		Weathered granite, mottled white, brown and black, mainly quartz and white weathered felspar.

B. Beryllium Distribution at the Bepe 2 Pegmatite

1. Pegmatite minerals and wall rocks

The Be contents of the principal components of the Bepe 2 pegmatite are presented in Fig. 9. The marginal aplite contains

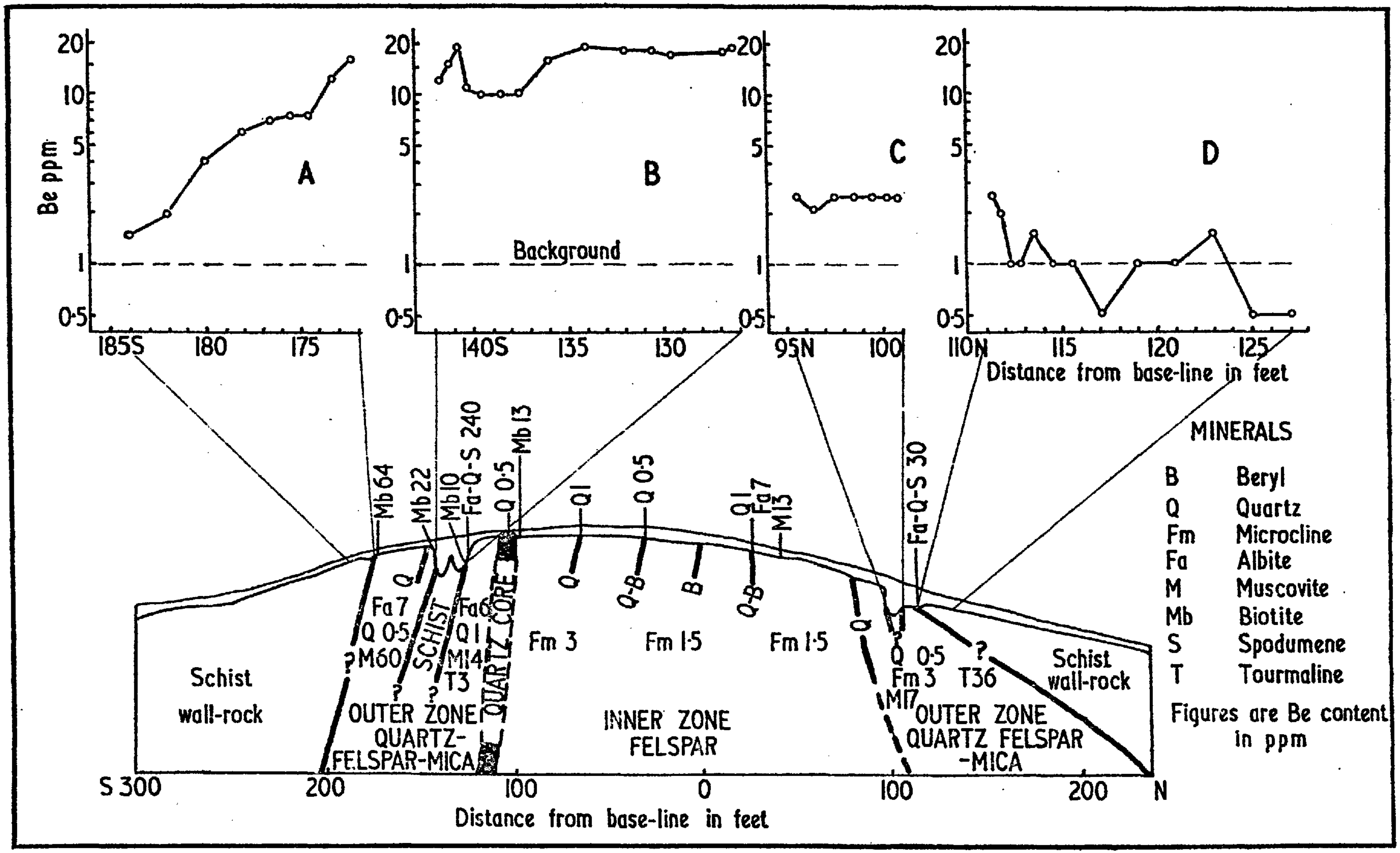


FIG.9. Be CONTENT OF PEGMATITE MINERALS AND SCHIST WALL-ROCK AT BEPE 2.
(Trench Traverse, see Fig.8)

30 p.p.m. Be (54 p.p.m. by gamma-neutron assay) at the northern boundary and 240 p.p.m. Be (230 p.p.m. by gamma-neutron instrument) at the boundary with the schist wedge on the southern side. These samples probably include fine discrete crystals of beryl. The amounts of Be in the minerals of the various zones are a little lower than those given by Solodov (1958) for a beryl-bearing pegmatite at Mongol Altai (Table 5).

TABLE 5

Be in beryl-pegmatite minerals

Mineral	Bepe 2				Mongol Altai (Solodov, 1958)
	Outer zone: medium- and coarse-grained pegmatite	Inner zone: massive microcline	Quartz core	Muscovite and albite replacement zones	
	p.p.m. Be				
quartz	0.5	0.5–1.0	0.5		2
microcline	3	1.5–3			5–10
albite	6–7	7		7	12–20
muscovite	14–60	13		13	32–46
tourmaline	3–36				
biotite (at contacts)	10–64			13	
Samples crushed to −100 microns					

The presence of small amounts of the element as an accessory constituent of the rock-forming minerals is further discussed in Section IV.

The tremolite-schist which is the host rock of the Bepe 2 pegmatite dyke contains 0.5-1.5 p.p.m. Be; granites in the area have a concentration of 1-4 p.p.m. Be. These values agree with the accepted average contents for these rock-types, viz:

		Be p.p.m.
Schists:	Rankama and Sahama (1949)	1
	Taylor (1955)	1
Granites:	Warner *et al.* (1959)	7
	Beus (1956b)	5
	Beus and Zahina (1956)	8
Granite minerals:	quartz, Beus and Zahina (1956)	0.2
	felspar, "	7
	micas, "	32

On the south side the dyke is bounded by schist with a Be content of 16 p.p.m. falling off rapidly to 1.5 p.p.m. at a distance of 12 feet from the contact (Fig. 9A). On the north side only a low value of 2.5 p.p.m. is evident at the contact, falling off to the background concentration of 1 p.p.m. within a distance of 1 foot (Fig. 9D). The average amount of Be in the schist wedge at 126S-142S is 16 p.p.m. (Fig. 9B), and in the schist wedge at 95-101N it is 2.5 p.p.m. (Fig. 9C). Up to 21 p.p.m. Be (average 5 p.p.m.) is reported by Stoll (1945) in the mica-schist wall-rocks of some New England pegmatites as a result of processes accompanying the emplacement of the pegmatites in which the Be ions have been accommodated in the space-lattices of common rock-forming minerals, possibly by means of recrystallisation of the minerals in the presence of solutions of appropriate composition. A similar process could have been in operation during the emplacement of the Bepe 2 pegmatite. However, the possibility that the presence of Be in the contact schist may be the result of secondary dispersion from the beryl-bearing quartz core cannot be overlooked.

2. Soils

(i) Background and threshold values

Very little information on Be in soil is available in the literature. The majority of reported values are spectrographic and the Be content is usually below the limit of detection. Mitchell (1955) gives the normal concentration as 0.2-10 p.p.m. with abnormal amounts as low as zero and as high as 100 p.p.m. Swaine (1955) reports 2-40 p.p.m. Be in soils from various parts of the world. In a recent study of East African soils Chamberlain (1959) found that soils from six provinces averaged 0.58 p.p.m. Be. Of the 131 samples analysed only 22 had more than 1.3 p.p.m. and three more than 5.1 p.p.m. The latter author considers the possibility that residual soils reflect the Be content of the rocks from which they are derived.

The local (within 2 miles of mineralisation) background Be values for soils over various rock types in the vicinity of the

Bepe 2 pegmatite fall within the range 1-4 p.p.m. (Table 6 and Figs. 10 and 22B); regional background concentrations are of the same order (Table 6 and Fig. 10).

TABLE 6

Background and threshold values in the -190 micron fraction of soils over various rock-types, Southern Rhodesia

Rock-type	Location	Figure	Be value p.p.m.	Threshold** value p.p.m.
			Local	
schist	Bepe 2, 2000S	22B	1.0	1.5
"	" 300N	10	1.5	
"	" ½ mile S.W.	10	1.0	
felspar with graphic quartz intergrowth	" 2000N	22B	3	3
sericitised quartzite	" 600-1500S	22B	2-4	4
granite	" ¾ mile N	10	2-4	4
"	" 2 mile S.W.	10	2-4	4
"	" 1½ mile S	10	3-4	4
dolerite	" ½ mile N	10	2	2
			Regional	
granite	Enkeldoorn*	10	1-4	4
"	Rusape*	10	1-2	2
"	Dorawa*	10	2-3	3
dolerite	"	10	2	2
"	Inuzura*	10	1-2	2

Samples - dry sieved, uncrushed

*For location see Fig. 2

**Threshold value is the upper limit of background fluctuation. In the present work it is determined by inspection of the data.

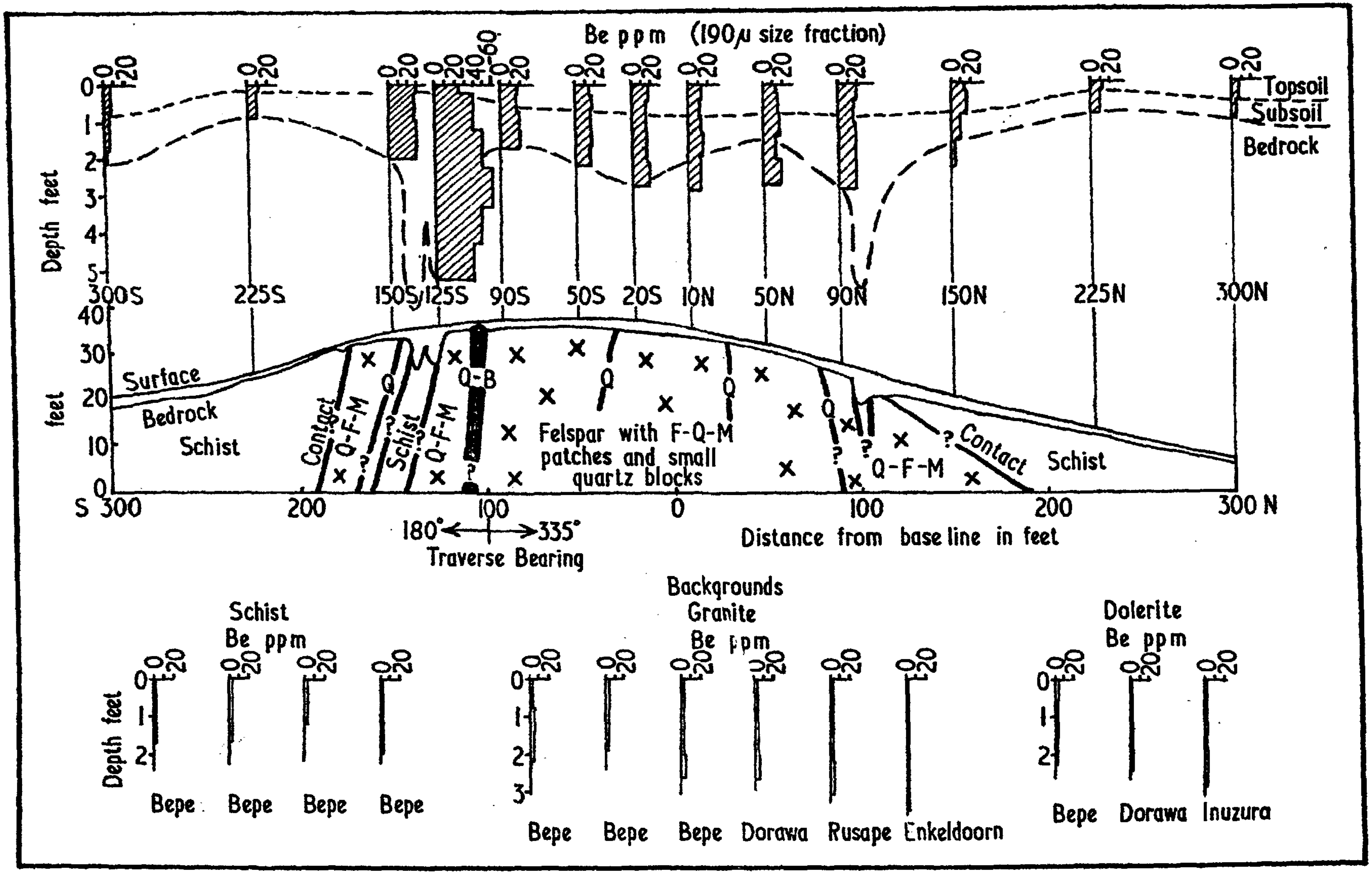


FIG. 10. DISTRIBUTION OF Be IN SOIL PROFILES, BEPE 2 AND BACKGROUND LOCALITIES.
(-190 micron size-fraction)
[Samples dry-sieved]

In the following discussion the figure of 1 p.p.m. will be used for the local background Be content of soils in the Bepe area because schist is the most prevalent background rock-type in the vicinity of the Bepe pegmatites.

Soils derived from granites appear to be slightly richer in Be than those above schists and dolerites and the Be content tends to increase with depth. Also the amount of Be increases markedly in the finer soil fractions of granitic soils, a feature which is absent in schist soils (Table 7).

TABLE 7

Be distribution in various size-fractions of background soils, Bepe area

Bedrock type	Depth (ins)	Material	Fraction (microns)							
			900-2000	470-900	190-470	100-190	80-100	20-80	2-20	0-2
			p.p.m. Be							
Granite, 2 miles S.W. of Bepe 2	0-5	Topsoil	1.5	1.0	1.0	1.5	1.5	2.0	3.5	4.0
	5-12	Subsoil	1.5	1.0	1.0	1.0	2.0	2.0	3.0	5.0
	12-24	"	2.0	1.5	1.5	2.0	2.0	2.0	3.0	5.0
Schist, 2000S, Bepe 2	0-12	Topsoil	1.5	1.5	1.0	1.0	1.5	1.5	1.0	0.5
	12-24	Subsoil	0.5	0.5	2.0	1.5	1.5	1.0	0.5	0.5

Samples treated by sedimentation, coarse fractions crushed.

(ii) Distribution in the soil profile

There are no distinct trends in the distribution of Be in the -190 micron fraction of soil samples from any one profile (Fig. 10; profile positions in Fig. 8).

A better understanding of the distribution of Be in the soil profiles is gained from a study of its content in the different size-fractions. Samples from selected profiles were treated by the sedimentation method described in Appendix I. The size-analysis data is given in Table 8 and the Be value of each fraction is presented diagrammatically in Fig. 11. Each point in Fig. 11 represents a Be value for material, the particles of which vary in size within the given limits*. The plots should strictly be in the form of histograms, but as it is not convenient to present data for several samples simultaneously on one such diagram the alternative linear plot has been adopted.

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*For nominal micron sizes of fractions see Appendix I.

TABLE 8

Mechanical composition of soil profile samples, Bepe 2

Profile	Depth (in)	Material	Fraction (microns)							
			900-2000	470-900	190-470	100-190	80-100	20-80 (fine sand)	2-20 (silt)	0-2 (clay)
			Weight per cent							
2000S Schist background	0-12	Topsoil	2.5	2.3	3.7	6.9	4.6	27.0	19.6	33.4
	12-24	Subsoil	8.6	4.0	2.8	4.0	2.3	16.9	25.7	35.7
300S on schist downslope from pegmatite	0-13	Topsoil	1.8	3.8	8.5	11.9	6.0	26.8	16.3	24.9
	13-26	Subsoil	3.3	3.0	3.9	9.8	5.5	21.9	19.2	33.4
	26-33	Subsoil	1.9	1.6	1.6	5.6	3.5	23.8	30.0	32.0
109S on pegmatite-beryl zone	0-6	Topsoil	9.7	11.1	15.5	16.1	6.7	18.0	10.5	12.4
	6-12	Subsoil	12.0	14.9	15.4	14.4	6.0	15.5	9.4	12.4
	12-20	Subsoil	18.4	20.4	14.5	10.8	4.6	12.3	7.8	11.2
10N on pegmatite-felspar zone	0-5	Topsoil	2.4	7.4	20.6	21.8	7.3	19.4	9.1	12.0
	5-10	Topsoil	2.1	9.5	21.3	18.0	7.0	18.8	9.8	13.5
	10-17	Subsoil	3.6	10.8	20.2	18.7	5.7	18.3	10.2	12.5
	17-26	Subsoil	8.2	16.7	21.1	13.8	4.7	12.7	8.1	14.7
150N on schist downslope from pegmatite	0-3	Topsoil	3.5	6.8	15.8	16.3	6.8	20.2	13.2	17.4
	3-20	Subsoil	3.9	8.8	13.1	10.9	4.5	19.5	14.7	24.6
	20-28	Subsoil	3.8	2.3	2.0	5.7	4.5	30.8	22.6	28.3
2 miles SW of Bepe 2, granite background	0-5	Topsoil	14.7	15.3	15.3	12.0	4.6	14.2	7.6	16.3
	5-12	Subsoil	18.5	17.5	12.7	8.9	3.4	11.6	8.1	19.3
	12-24	Subsoil	27.6	20.2	12.5	7.8	2.8	9.9	7.7	11.5

Samples treated by sedimentation

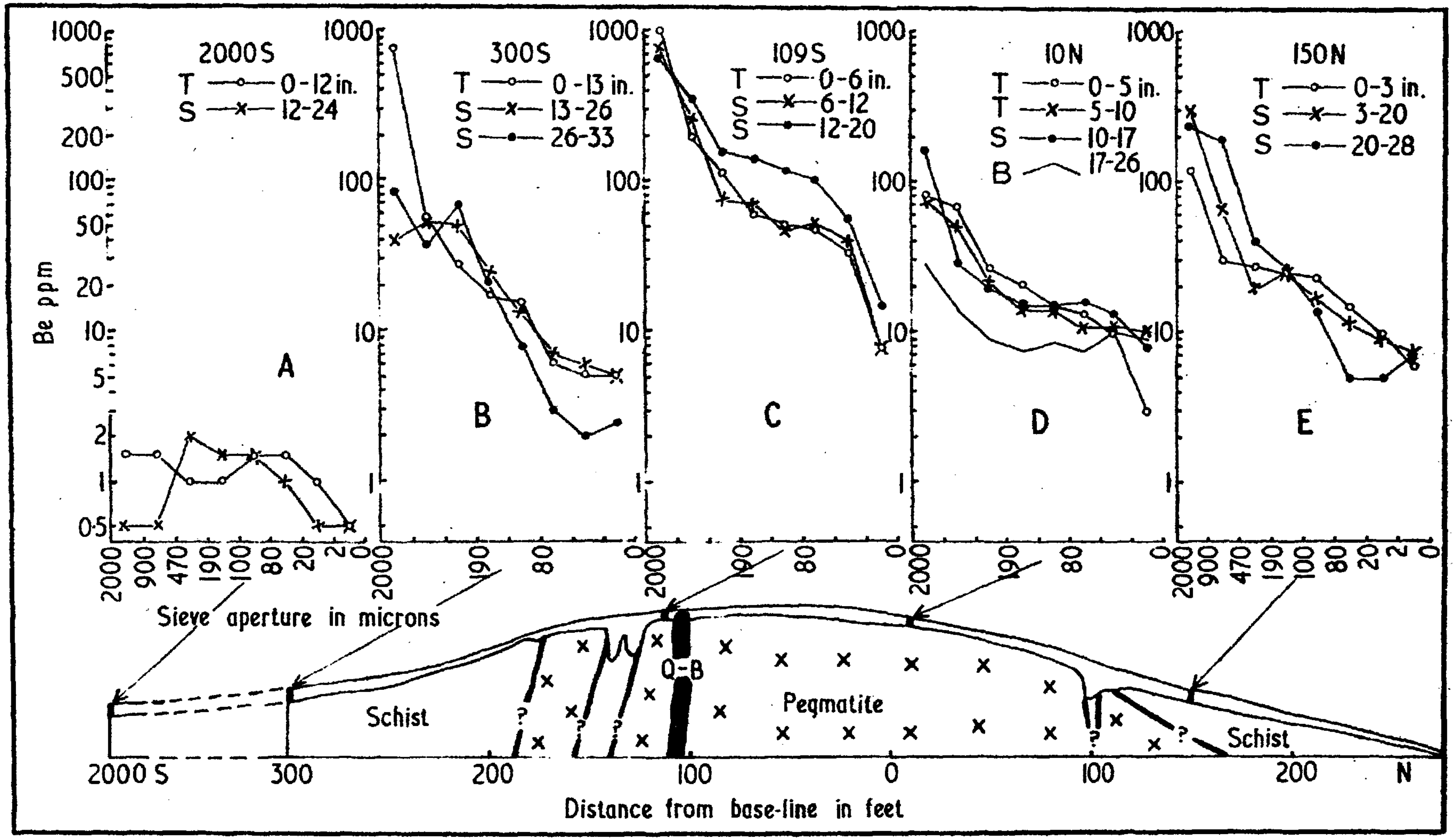

FIG. 11. Be DISTRIBUTION IN SIZE-FRACTIONS OF SOIL PROFILE SAMPLES, BEPE 2.
(T = topsoil ; S = subsoil ; B = weathered bedrock)
[Samples treated by sedimentation]

A study of the data in Table 8 indicates that:-

(a) There are, in general, 2-3 times the amount of fine sand, silt and clay-size material in soils derived from schist than in soils derived from pegmatite;

(b) There is very little variation in the amount of clay-fraction with depth in any particular profile. The lower clay content of surface samples from profiles 300S and 150N, in comparison with that in deeper samples, is due to the influence of upslope pegmatite soils moving downslope by surface creep, as shown by the higher Be contents of material of the upper horizons (Figs. 11B and 11E). However, downward elutriation of fine material may take place to some extent, though a comparison with the background schist profile data cannot be made as the latter profile is situated on almost flat terrain;

(c) The effect of pegmatitic material derived from upslope on the upper samples from profiles 300S and 150N is particularly illustrated in the 470-900, 190-470 and 100-190 micron fractions which occur in much greater amounts in the upper samples in comparison to their amounts in deep samples.

The main features observed in the profile values presented in Fig. 11 are as follows:

(a) The range of background concentrations in the various size-fractions of soil over schist is 0.5-2 p.p.m. Be (see also Table 7) with an average content of 1 p.p.m.

(b) In general the highest Be values occur in the coarsest fraction of an anomalous soil, irrespective of sample depth, and the values progressively decrease with diminishing particle size. The decrease is more pronounced in anomalous profiles above schist bedrock than in those over pegmatite, particularly in the deepest samples (Figs. 11B and 11E). This feature is due to the fact that, in contrast to pegmatite, the schist bedrock weathers to a soil in which -100 micron material predominates. Consequently, on mixing with anomalous pegmatitic soil, there is much less dilution in the coarser fractions than in the finer sizes. The feature is better demonstrated in Fig. 12 by a rearrangement of the plots shown in Fig. 11. Within each profile the Be values for each size-fraction have been combined on a weight basis to give a representative concentration for each fraction in the profile. At all points the amounts of Be decrease with diminishing particle-size. In Fig. 12B, profile 109S (beryl zone) has been omitted to emphasise the comparison between the profile over pegmatite (10N) and those downslope over schist (300S and 150N). The change in slope of the lines representing the three fine fractions in comparison to those of the coarser fractions illustrates the relatively marked effect of dilution of fine-grained anomalous material by the schist weathering products as compared to the coarser fractions.

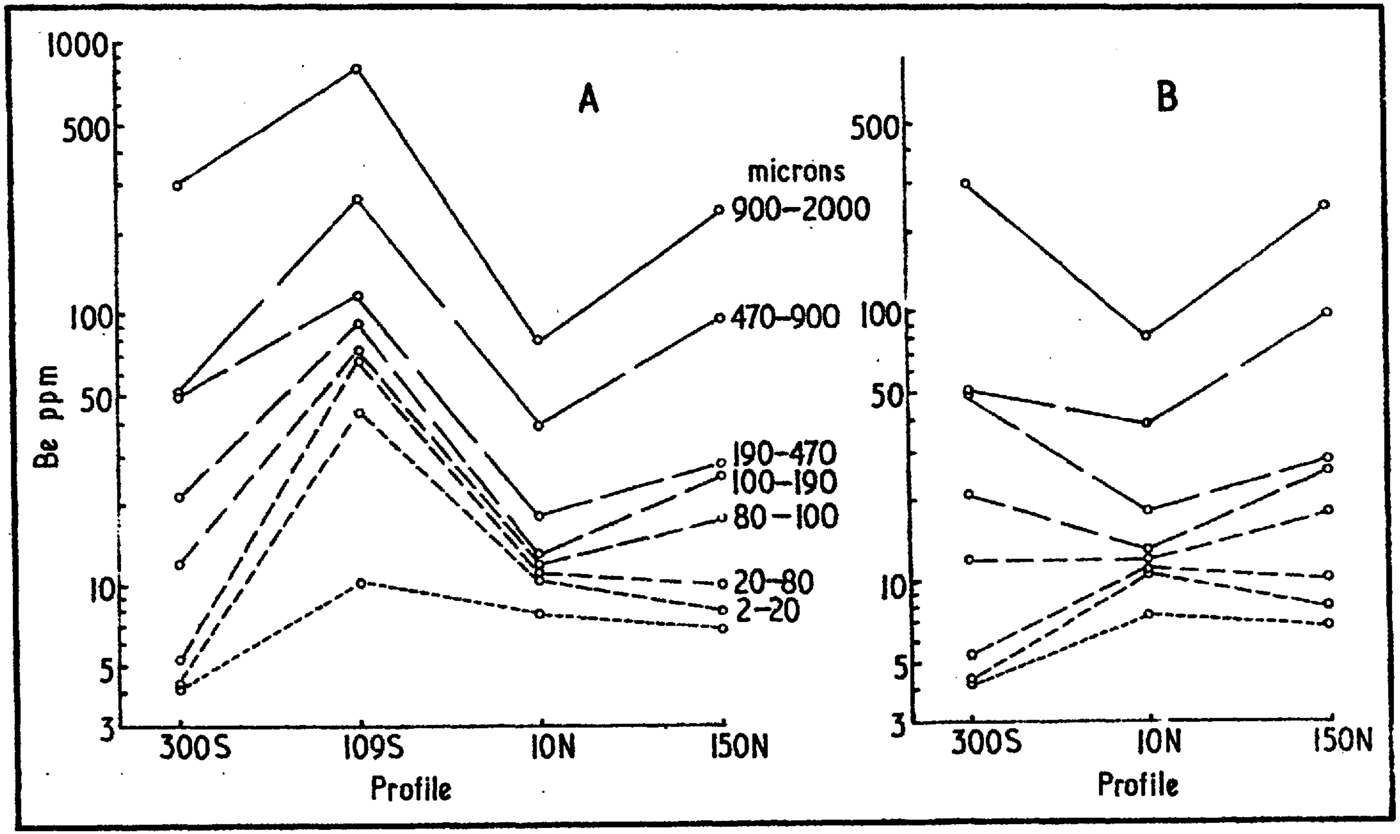

FIG.12. Be DISTRIBUTION IN SIZE-FRACTIONS OF COMPOSITE SOIL PROFILE SAMPLES, BEPE 2.
[Samples treated by sedimentation]

(c) For any given size-fraction the Be content of soil over the beryl zone is much higher than that obtained at other positions. This feature is emphasised in Fig. 12A.

(d) In general the deepest sample of the profile over the beryl zone (109S) contains the greatest amount of Be whereas the deepest sample of the felspar zone profile (10N) contains the least amount of the metal. The difference is due to the low Be content of the felspar (1.5-3 p.p.m.) and the effect of mixing with high-tenor soils moving downslope by soil creep (discussion in Section IV p.154).

(e) The lowest Be values in the samples are associated with the clay-fractions, a fact which possibly indicates that there is little, if any, decomposition of beryl, since conditions are such that any Be mobilized in this way would be expected to reprecipitate and occur preferentially in the clay-size fraction (see discussion in Section IV, p. 149), as appears to be the case with the Be released from felspars in background granitic soils (Table 7). The distribution pattern of the Be values is consistent with the mechanical decomposition of the beryl.

(f) No evidence of a marked concentration of Be in the surface horizon, where organic matter is present, is shown in any of the profiles. In fact, in profile 10N where the topsoil colour indicates the presence of large amounts of organic matter, the Be content of the clay fraction is exceptionally low.

Similar features to those described above are shown by the results obtained on the different size-fractions of subsoil samples from the 4 profiles illustrated in Fig. 13. On the right-hand side of this figure a comparison is made between the weighted mean values of the +190 and -190 micron fractions of each sample, and from these it may be concluded that although Be anomalies can be detected readily by testing the -190 micron fraction, much greater contrast is achieved by testing the +190 micron fraction. This conclusion applies particularly in the vicinity of beryl zones and the schist soils downslope. Although it is valid under the conditions which prevail in the Bepe area it may not apply in other areas under different conditions.

(iii) Lateral distribution

Reference to the lateral distribution of Be in soils has already been made in the previous section where it has been shown that samples over the beryl zone contain greater amounts of Be than those collected elsewhere, and that anomalous values due to pegmatitic material are detected downslope in the soil above barren schist bedrock.

The continuity of the Be values in soils at Bepe 2 was investigated by collecting and testing samples from points on a

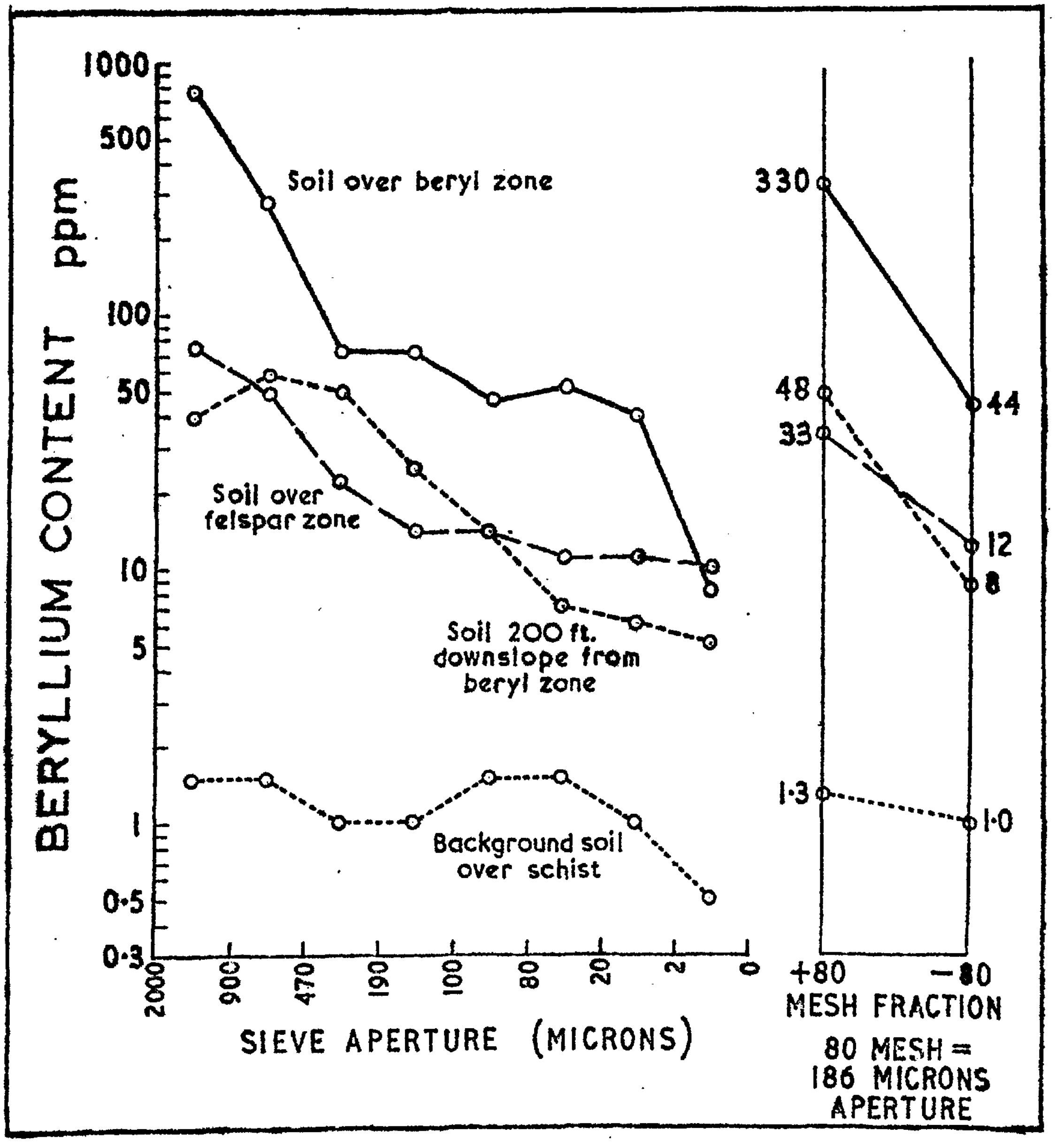

FIG.13. DISTRIBUTION OF Be IN SIZE-FRACTIONS OF SUBSOILS, BEPE 2. [Samples treated by sedimentation]

series of traverses across the pegmatite (Fig. 8). The results obtained along Traverse O (Fig. 14) show the following points of interest:

(a) A distinct anomaly with its peak coinciding with the pegmatite outcrop is detected whichever size-fraction is tested;

(b) The anomalies diminish rapidly to background (1 p.p.m.) at 200S. The explanation is found in Fig. 8 where it may be observed that a change in direction of maximum slope around 200S causes anomalous material to be carried away to the south-west, whereas the traverse continues to the south-east over soil derived from barren schists;

(c) The higher background values (up to 3 p.p.m. Be) between 400S, and 800S are due to a change in bedrock lithology from schist to sericitic quartzite, as mentioned in Table 6;

(d) The lateral dispersion of anomalous Be is more extensive along the northern portion of the traverse. With a threshold (i.e. the upper limit of background fluctuation, see Table 6) of 1.5 p.p.m. for the schist, it is observed that the coarse-fraction anomaly extends to 600N, the intermediate fraction anomaly to 700N and the fine-fraction anomaly to 500N. It is apparent that the anomalies of maximum width are obtained by testing the coarser fractions of the soils;

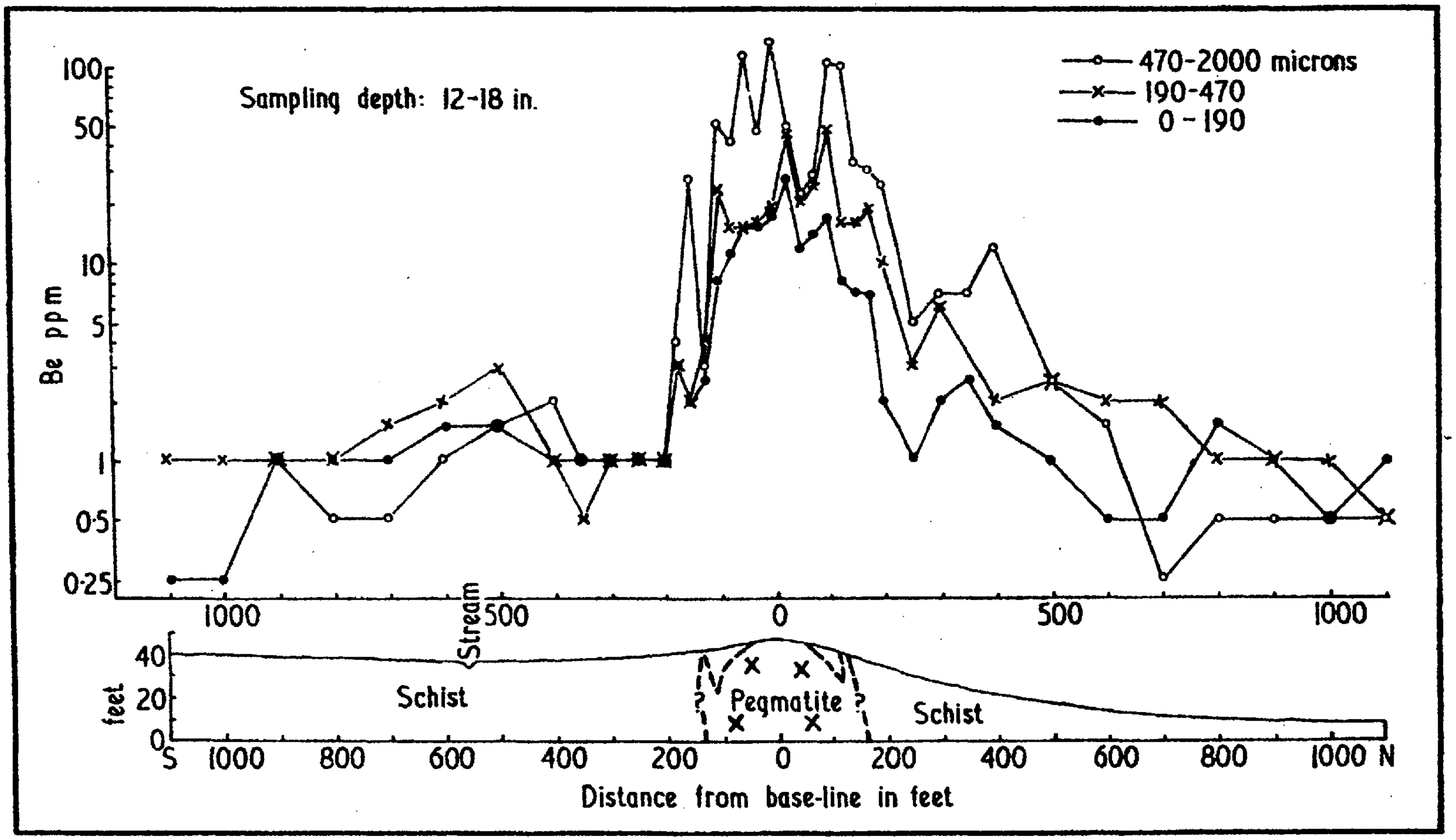

FIG. 14. Be DISTRIBUTION IN SIZE-FRACTIONS OF SOILS, TRAVERSE 0, BEPE 2.
(Samples collected by J. S. Webb)
[Samples dry-sieved]

(e) In addition to broadening the anomaly, analysis of the coarsest fraction also gives the highest peak values. Thus, values up to 100 p.p.m. are recorded in the 470-2000 micron fraction in comparison to 15-20 p.p.m. Be in the -190 micron fraction;

(f) The Be content of all fractions is low above the schist wedge at 50-75N, but it increases again over the narrow pegmatite offshoot at 100-125N. There is a similar peak in values at 150S, possibly due to a concealed suboutcropping offshoot of pegmatite. A small pegmatite outcrop 100 feet to the east of 150S may be an extension of such an offshoot;

(g) The coarse-fraction values exhibit much greater variations between samples than do the intermediate and fine fractions. Homogeneity and representivity of the samples are discussed later on p. 64.

The position of Traverse 0 is disadvantageous in that it crosses the extreme eastern end of the dyke from which the dispersion of anomalous material is limited in the directions of the traverse due to a change of slope. More interesting traverses for this study would have been the Trench Traverse to the northwest and Traverse 150W to the south from the dyke. However soils along each of these traverses were disturbed by cultivation at distances greater than 500 feet from the base-line.

The results of detailed sampling at 10 foot intervals along Traverse A, situated entirely on the pegmatite, are presented in Fig. 15. It is observed that:

(a) The values given by the coarse fraction (470-2000 microns) fluctuate markedly in comparison with those of the other two fractions. These variations are possibly due to poor representivity (see p. 64);

(b) The fine fraction values are very consistent;

(c) There may be a general trend showing a trough near the centre of the traverse with peaks on either side, a trend best represented by the intermediate fraction (190-470 microns). The peak anomalies detected in the different size-fractions are neither strongly developed nor do they coincide at any single point. It is assumed, therefore, that the traverse does not cross a well-defined beryl zone, although the values may be influenced by proximity to such a zone.

Traverse B gave similar results (Fig. 16):

(a) The values obtained from the coarse fraction again fluctuate greatly;

(b) There is a decrease in Be content as particle-size decreases; the coarse fraction values being up to 6-times those of the corresponding fine fractions;

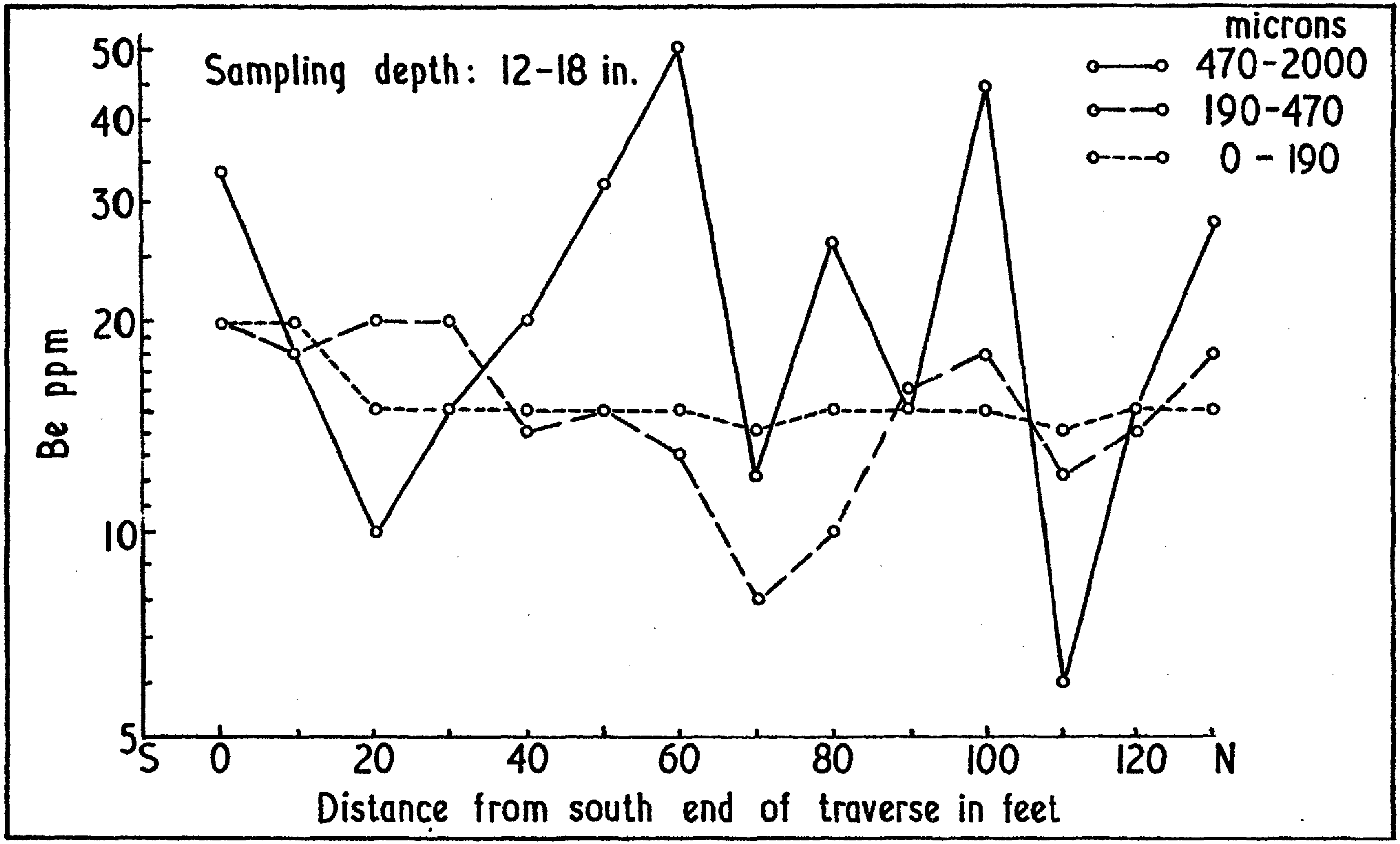

FIG. 15. DISTRIBUTION OF Be IN SIZE-FRACTIONS OF SOILS, TRAVERSE A, BEPE 2. (Samples collected by J.S.Webb) [Samples dry-sieved]

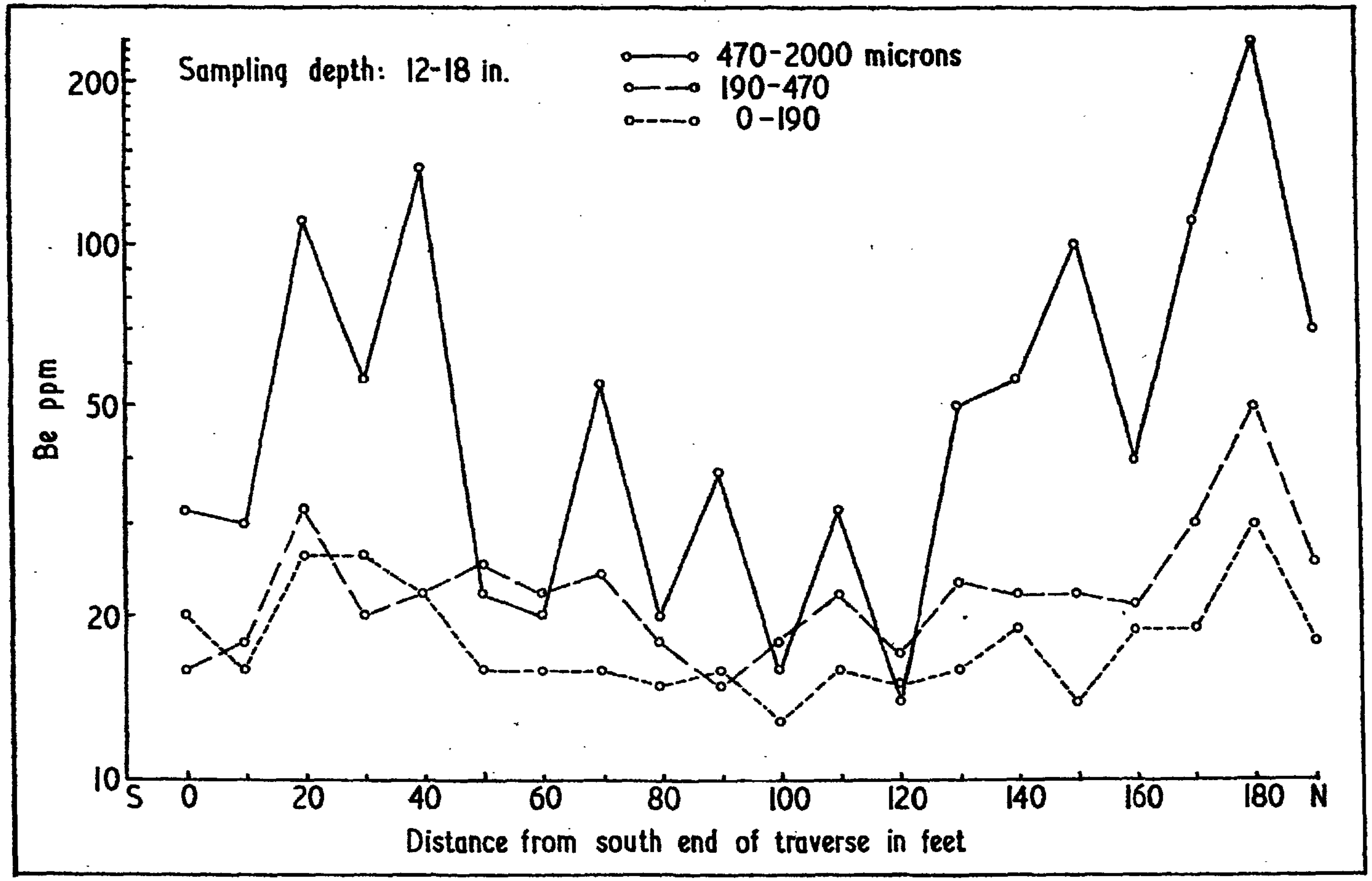

FIG.16. DISTRIBUTION OF Be IN SIZE-FRACTIONS OF SOILS, TRAVERSE B, BEPE 2.
(Samples collected by J.S.Webb)
[Samples dry-sieved]

(c) There is a general trough between two peaks, represented in all fractions but emphasised in the coarse fraction. The broad peak at the southern end of the traverse possibly reflects an underlying beryl-bearing muscovite replacement complex observed in the pegmatite, while the narrow higher peak at the northern end may be due to beryl associated with the quartz core (Fig. 8). It is apparent that all size-fractions may reflect zoning within the pegmatite bedrock and that this is best shown in the coarse fractions.

Only the -190 micron fractions of the soil samples were tested in the two traverses 150W and 250W which cross the central portion of the dyke. The results obtained along Traverse 150W, illustrated in Fig. 19A, show the following features:

(a) A broad anomaly with values averaging 20 p.p.m. Be covers the entire width of the pegmatite;

(b) An anomaly peak of 80 p.p.m. Be occurs at 110S above the beryl zone;

(c) The anomalous values decrease to background 150 feet away from the southern pegmatite boundary and 300 feet from the northern boundary.

A similar Be distribution is apparent in Traverse 250W (Figs. 20A and 20C). In this case, the beryl zone occurs at 10S where it is represented by high values in the subsoil, although only low values are present in the surface soil. In addition a broad but weak peak between 120S and 140S possibly represents a beryl-bearing muscovite replacement zone at bedrock.

The main feature observed in the above results for the -190 micron fraction of the soils is the general regularity and homogeneity of the values across the full width of the dyke. This regular pattern is only interrupted by high peaks over the main beryl zone and broader peaks over the muscovite replacement zone. The presence of occasional coarse fragments of beryl, which are scattered throughout the overburden, do not appear to affect the distribution of Be in the fine soil fraction.

Sizing tests were carried out on the preliminary samples at a time when the only analytical method available was a general semi-quantitative spectrographic technique. While the results demonstrated the existence of anomalies justifying the subsequent detailed examination, it is now apparent that the spectrographic method employed failed to bring out the significant differences between the different size-fractions. For this reason routine samples collected and analysed in the field, in order to control the selection of critical samples for the detailed laboratory work, were sieved to -190 micron size. However it should be possible to achieve Be anomalies of maximum contrast and width by separating the 80-190 micron fraction for analysis. This operation would remove the low-tenor fine sand, silt and clay material and it may only be applicable in areas where the mineralization and environment are similar to those at Bepe.

The effect of taking only the 80-190 micron fraction was tested on samples from a section of Traverse O. The results, tabulated in Table 9, show that the anomaly width at threshold level (2.5 p.p.m.) has increased from 250 feet beyond the pegmatite boundary (0-190 micron fraction) to a point 500 feet beyond the boundary (80-190 micron fraction), and in addition the peak anomaly contrast is increased by approximately 30 per cent.

It should be noted that the results referred to in this section were obtained on samples that had been dry-sieved and not treated by the dispersion and sedimentation processes used for the complete size analyses of soil profile samples. The effect of aggregated fine material that is not dispersed by dry sieving is discussed in Appendix I.

TABLE 9

Magnitude and persistence of a Be anomaly, using the 80-190 micron fraction of soils, Traverse O, Bepe 2

Sample point	p.p.m. Be		Relative increase in magnitude $(\frac{B}{A})$
	A -190 micron fraction	B 80-190 micron fraction	
1100N	1	1	1
1000	0.5	1.5	3
900	1	1	1
800	1.5	1.5	1
700	0.5	1.5 background	3
600	0.5	2 anomaly	4
500	1	2	2
400	1.5 background	2	1.3
350	2.5 anomaly	5	2
300	2	5	2.5
250	1	2	2
200	2	6	3
175	7	12	1.7
150 schist	7	12.5	1.8
125 pegmatite	8	12.5	1.6
75	14	17	1.2
50	12	17	1.4
25N	27	35	1.3

Samples dry-sieved

(iv) The effect of crushing samples

In order to achieve complete chemical decomposition of rock and soil samples with ammonium fluoride it is necessary to grind the coarse fractions to a powder with a particle-size preferably less than 100 microns. The effect of crushing on the Be values of the 470-2000 and 190-470 micron fractions of soils from a section of Traverse O is illustrated in Fig. 17 and Fig. 18, respectively. Considerable differences in values between crushed and uncrushed samples are evident for coarse material of 470-2000 micron size and the differences are much less for the 190-470 micron fraction. A similar comparison is made for -190 micron fraction samples from Traverse O in Table 10.

TABLE 10

Comparison of Be values for crushed and uncrushed -190 micron fraction of soil samples, Traverse O, Bepe 2

Sample point	Crushed value p.p.m. Be	Uncrushed value p.p.m. Be	Percentage difference on crushing
200N	2	2	0
150	6	7	-14
125	9	8	12
100	20	17	18
75	12.5	14	-11
50	10	12	-17
25N	25	27	-7
0	17	17	0
Samples dry-sieved			

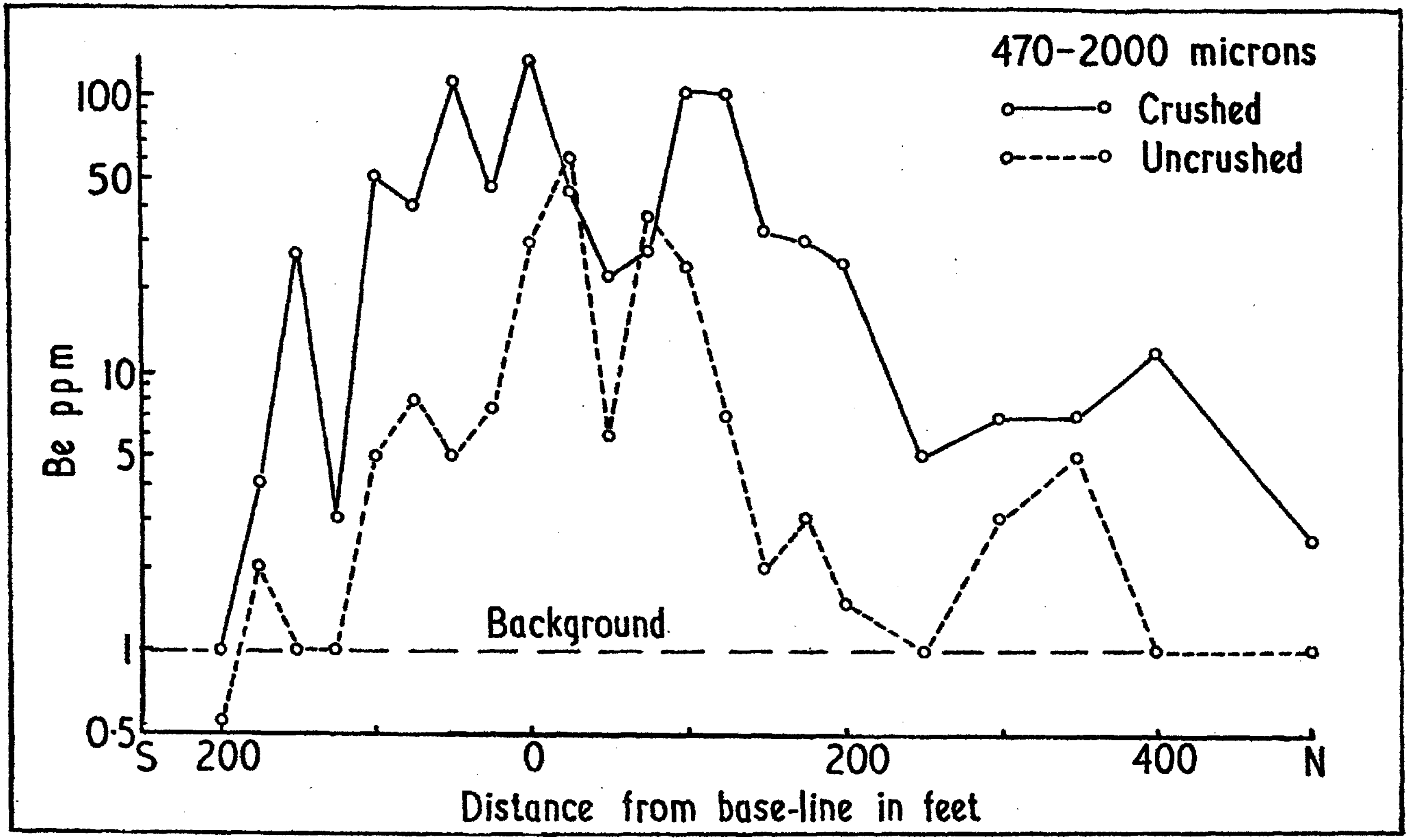

FIG.17. EFFECT OF CRUSHING THE 470-2000 MICRON FRACTION OF SOILS, TRAVERSE O, BEPE 2. [Samples dry-sieved]

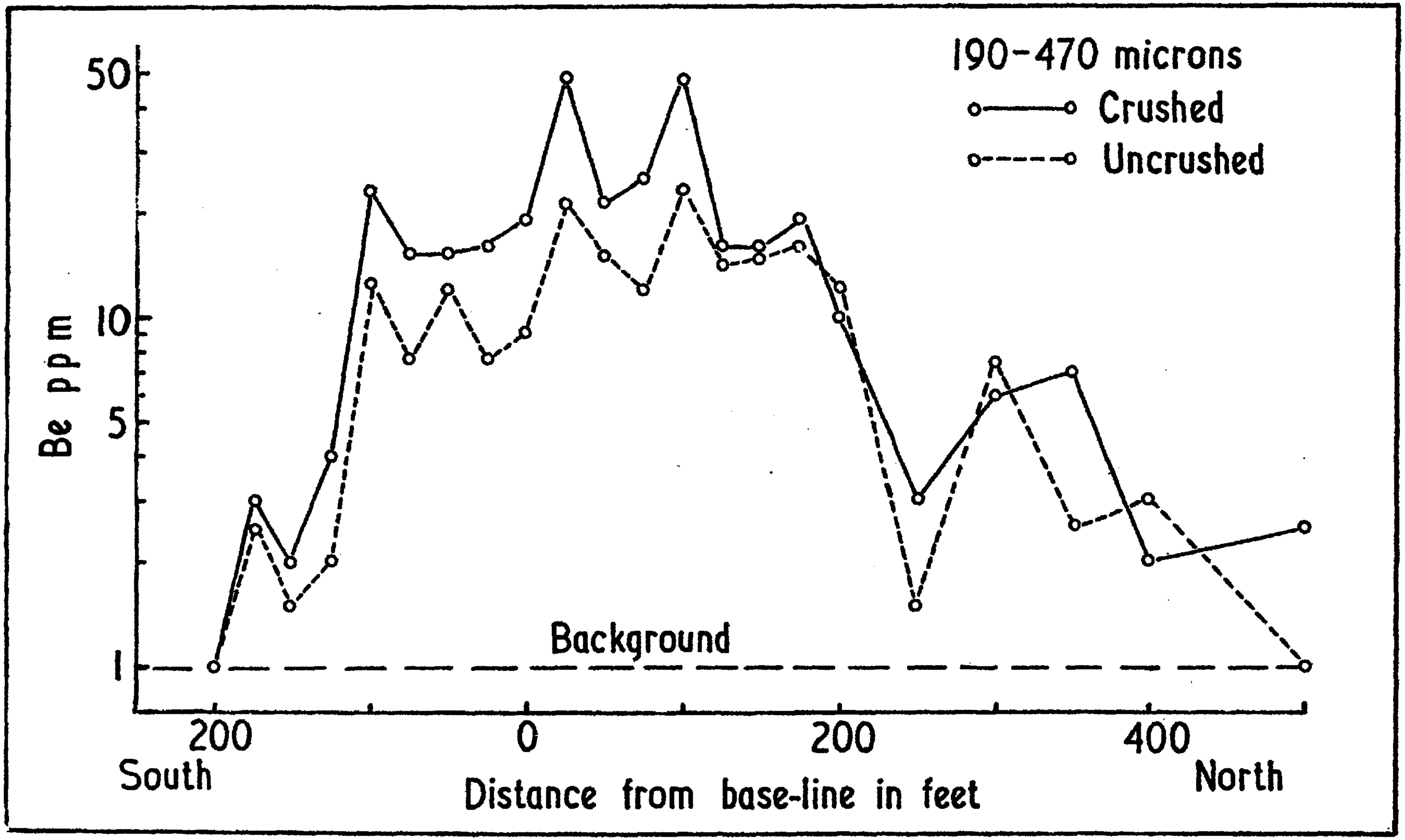

FIG. 18. EFFECT OF CRUSHING THE 190-470 MICRON FRACTION OF SOILS, TRAVERSE O, BEPE 2. [Samples dry-sieved]

The difference between values on crushing for each of the three size-fractions considered above are compared in Table 11. The percentage variation for the two coarse fractions is calculated from the values presented in Figs. 17 and 18, and that for the fine fraction from the values given in Table 10.

TABLE 11

Comparison of percentage difference on crushing various size-fractions of samples from Traverse O, Bepe 2

Size-fraction (microns)	Percentage difference on crushing	
	Range	Mean
470-2000	10-2000	700
190-470	0-180	70
0-190	0-18	10

The following points emerge from the above considerations:

(a) For most of the coarse samples it is evident that crushing has a significant effect which increases with increasing original particle-size;

(b) The percentage difference for the -190 micron fraction is less than the analytical precision of ±20 per cent, and the variations can be attributed to analytical factors rather than to those due to crushing;

(c) It is also evident from the above data that, if low values due to inefficient sample attack are to be avoided, the only material which can be tested without preliminary grinding is that with particle-size less than 190 microns.

It should be noted that, except for the experimental values for uncrushed coarse fractions given above, all the results given elsewhere for fractions coarser than 190 microns refer to crushed material.

(v) Representivity

Not all of the results obtained above on the coarse fractions can be entirely explained by incomplete attack of the uncrushed material. For instance, two uncrushed 470-2000 micron fraction values exceed those for the ground samples (see Fig. 17), and three uncrushed 190-470 micron fraction values are greater than those of the corresponding crushed samples (Fig. 18). These results are considered to reflect original variations in the total Be content, indicating a significant lack of representivity for the samples involved. This feature of poor representivity has been mentioned previously on p. 57 in relation to the large variations in the values of adjacent coarse-fraction samples (Figs. 15 and 16); it may be a direct result of the small weight of sample taken for crushing before analysis.

The sample weight required to achieve a definite level of representivity at a specified metal concentration has been studied by Pierre Gy*, who has shown that the relationship between the size-range and weight of a sample can be written for all practical purposes as follows:

$$\frac{P^1 \sigma^2}{d^3} = C \text{ (constant), where}$$

P^1 is the weight of the sample,

σ^2 is the variance of the percentage error, calculated on the true assay of the sample,

d is the size of the largest particles present, and

C is a constant which is characteristic of the nature of the material sampled. For the present study it is assumed that the Be content of a sample is due to discrete fragments of the mineral beryl.

Gy supplies a nomogram for the calculation of any one variable, after fixing the other two. The constant C is readily determined from a chart on the nomogram.

For the present purpose the value of "d" is taken as the mean particle-size, in microns, for each range considered. The other variable fixed is σ^2, or in effect 2σ which is the percentage error of the Be value of the sample which will not be exceeded 95 times out of 100. The sample weights required to satisfy various values of "d" and 2σ are given in Table 12, in which

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*GY, PIERRE: Sampling Nomogram. Minerais et Métaux, Société Anonyme - Paris. Service Technique: 28 Rue Arthur Rozier, Paris XIX.

TABLE 12

Weight of sample needed to give a required sampling precision, at the 100 p.p.m. Be level (0.2 per cent beryl)

Fraction (microns)	Mean particle-size (microns) (d)	Weight of sample (g)							
		Required precision at the 95 per cent confidence level (2σ)							
		± 1%	± 2%	± 5%	± 10%	± 20%	± 40%	± 80%	± 100%
2,000-6,300	4,100	300,000	80,000	12,000	3,000	800	200	50	30
470-2,000	1,250	10,000	2,500	400	100	25	6	1.5	1.0
190- 470	330	200	50	8	2	0.5	0.12	0.03	0.02
0- 190	85	3	0.75	0.12	0.03	0.008	0.002		
2,000-6,300	4,100	300,000	80,000	12,000	3,000	800	200	50	30
900-2,000	1,450	15,000	4,000	600	150	40	10	2.5	1.5
470- 900	680	1,500	400	60	15	4	1	0.25	0.15
190- 470	330	200	50	8	2	0.5	0.12	0.03	0.002
100- 190	145	14	3.5	0.6	0.15	0.04	0.01	0.002	
80- 100	90	3	0.8	0.12	0.03	0.008	0.002		
20- 80	50	0.5	0.12	0.02	0.005	0.002			

a true sample assay of 100 p.p.m. Be (0.2 per cent beryl) is assumed. For a true Be content of 10 p.p.m. the sample weight must be 10 times as great as that shown; for a Be content of 1000 p.p.m. Be only 1/10th of the weight given in the table would be necessary, etc.

The poor representivity of coarse fractions was demonstrated by analysing duplicate crushings of the 470-2000 micron fraction of samples from Traverse 0 (Table 13). By considering the weight of sample taken (av. 5 g) and the mean level of the Be content, it is possible to calculate the expected sampling precision from Table 12. The percentage variations about the means, given in Table 13, should, of course, be much less than the calculated sampling precisions. Only at sampling point 25N is there an appreciable discrepancy. The weight of sample which would be required to give a sampling precision of ±20 per cent is also shown in Table 13.

TABLE 13

Variations between duplicate crushings of the 470-2000 micron fraction of samples from Traverse 0, Bepe 2

(5g sample taken for analysis)

Sample point	p.p.m. Be			Percentage variation about mean	Sampling precision at 95% confidence level (from Table 12) (%)	Sample wt. to give ± 20% sampling precision (g)
	1st value	2nd value	Mean			
400N	12	1	6.5	85	> 100	400
350	7	44	25	75	80	100
300	7	6	6.5	10	> 100	400
250	5	2.5	4	40	> 100	625
200	25	15	20	25	100	125
175	30	38	34	10	80	75
150	32	38	35	10	80	75
125	100	20	60	65	60	40
100	104	160	130	20	40	20
75	28	22	25	10	90	100
50	22	70	46	50	70	50
25N	45	230	140	70	40	18
0	130	100	115	15	40	25
25S	46	76	61	25	60	40
50	112	40	76	50	50	35
75	40	52	46	15	70	50
100	50	32	41	20	70	60
125	3	3	3	0	> 100	850
150	27	2.5	15	80	> 100	170
175	4	2.5	3	25	> 100	850
Samples dry-sieved						

A series of tests on the size-fractions of one sample (no. 182) was carried out in order to demonstrate the effect on representivity of testing only small samples. After taking initial grab samples for analysis, the various fractions were treated as follows:

Fraction, microns	Treatment
2000-6300) 470-2000) 190-470)	Each fraction quartered into portions A, B, C and D: A was not crushed before analysis; B was crushed and analysed in duplicate; C was split into equal portions C1 and C2; each was ground and analysed separately; D was quartered into portions D1, D2, D3 and D4; each was crushed and analysed separately;
-190	Quartered into sections A, B, C and D; each was analysed separately without crushing.

The results for the 2000-6300, 470-2000, 190-470 and -190 micron fractions are given in Tables 14, 15, 16 and 17 respectively.

TABLE 14

Representivity tests for the 2000-6300 micron fraction of sample no. 182

Portion	Weight (g)	p.p.m. Be	Percentage variation about mean*	Sampling precision at 95% confidence level (from Table 12) (%)
A(uncrushed)	10.2	40		
<u>Crushed</u>				
B	10.5	560; 640	50	90
C1	4.5	1000	>100 (150)	>100
C2	4.5	6	100	"
D1	2.3	7	100	"
D2	2.6	5	100	"
D3	2.9	180	60	"
D4	2.7	400	4	"

*The weighted mean value is 415 p.p.m. Be

TABLE 15

Representivity tests for the 470-2000 micron fraction of sample no. 182

Portion		Weight (g)	p.p.m. Be	Percentage variation about mean*	Sampling precision at 95% confidence level (from Table 12) (%)
Grab samples, (separate crushings)	a	5.9	160, 150, 130, 110	40,30,15,4	40
	b	2.8	100, 110	10, 4,	60
	c	2.8	25, 30	80, 75	60
<u>Uncrushed</u>					
A		5.6	30;15; 5	-	-
<u>Crushed</u>					
B		6.4	96, 70, 84, 80,	15,40,25,30	40
C1		2.4	40, 44,	65,60	70
C2		2.9	300, 200	160,75	60
D1		1.4	60, 60	45,45	80
D2		1.6	20, 25	80,80	80
D3		1.3	350, 280	200,150	80
D4		1.5	220, 180	75, 55	80
B		6.4	82	30	40
C		5.3	156	35	40
D		5.8	143	25	40

*The weighted mean value is 114 p.p.m. Be

TABLE 16

Representivity tests for the 190-470 micron fraction of sample No. 182.

Portion	Weight (g)	p.p.m. Be	Percentage variation about mean*	Sampling Precision at 95% confidence level (from Table 12) (%)
Grab sample, crushed.	3.4	19	10	15
Uncrushed				
A	4.3	20, 24, 20	-	-
Crushed				
B	4.3	23, 26	7, 20	15
C1	2.3	23	7	20
C2	2.3	20	7	20
D1	1.1	18	16	30
D2	1.0	20	7	30
D3	1.0	22	2	30
D4	1.1	18	16	30

*The weighted mean value is 21.5 p.p.m. Be

TABLE 17

Representivity tests for the -190 micron fraction of sample No. 182

(Samples uncrushed)

Portion	Weight (g)	p.p.m. Be	Percentage variation about mean*	Sampling Precision at 95% confidence level (from Table 12) (%)
Grab samples	0.5g each	16, 20, 17, 17, 18.	9, 14, 3, 3, 3.	6
A	1.6	18	3	6 (0.5g uncrushed sample analysed)
B	1.7	17	3	6 "
C	1.3	17	3	6 "
D	1.4	17	3	6 "

*The weighted mean value is 17.5 p.p.m. Be

The results given in Tables 14, 15, 16 and 17 are summarised in Table 18.

TABLE 18

Comparison of representivity data for different size fractions of sample No. 182

Fraction (microns)	Total weight of sample studied (g)	Mean Value (p.p.m. Be)	Sampling precision with given total sample weight (%)	Weight of sample req'd to give ± 20% sampling precision (g)	Representivity of sample studied
2000-6300	30	415	60	200	Poor
470-2000	17.5	114	30	25	Reasonable
190-470	13	21.5	7	2	Good
-190	6	17.5	6 (0.5g uncrushed sample analysed)	0.04	Excellent

The sampling precisions given in the tables above are due to sampling only; they do not include variations due to the analytical method.

It may be concluded that when analysing coarse fractions the major source of error is due to poor sampling precision, whereas in the case of fine fractions the analytical variation is predominant. It may be noted, however, that in all cases where replicate determinations are made on any one particular crushing of a coarse fraction the replicate values fall within the analytical variation from the mean value for that crushing. This indicates that grinding evenly distributes the smaller particles of beryl throughout the sample.

In view of the large sample weight and fine crushing that would be required in order to obtain representative material, the 2000-6300 micron fraction was not considered further in the subsequent investigation.

The degree to which the Be value of one sample can be considered as representative of the Be content of the soil within the surrounding area was tested by taking a pattern of closely spaced samples radiating from a central point. The centre sample was located at 25N 300W and samples were collected at intervals of $1\frac{1}{4}$, $2\frac{1}{2}$, 5, 10, 15, 20 and 25 feet on four lines at right angles to each other. The results are presented in Table 19.

TABLE 19

Areal representivity of the -190 micron fraction of soil samples, Bepe 2

Distance from central point (feet)	Direction of Traverse			
	N.E.	N.W.	S.W.	S.E.
	Be p.p.m.			
$1\frac{1}{4}$	23	16	24	19
$2\frac{1}{2}$	21	13	23	22
5	17	13	27	14
10	24	16	13	14
15	22	19	16	17
20	21	15	17	17
25	17	18	14	13

Value at central point = 22 p.p.m. Be

The radial pattern lies completely above pegmatite bedrock, possibly above a muscovite-replacement zone. The mean value is 18 p.p.m. Be and all the values fall within the limits 18 ± 6 p.p.m. The analytical precision of ±20 per cent could conceivably account for the values with the range 18 ± 4.5 p.p.m. Some of the variations may be due to changes in tenor of Be in the soil, but they are only of a minor nature. Any one sample is therefore reasonably representative of the soil for at least 25 feet around it.

Such consistent distributions of values do not persist, however, in the vicinity of the beryl-rich zone where four-fold variations may occur over a distance of 5 feet or less.

(vi) Results achieved with alternative analytical methods

Spectrographic analyses for Be in samples from Traverse 150W were carried out by J. D. Kerbyson (Kerbyson and Webb, 1959). The values for the -190 micron fractions are presented in Fig. 19B. Apart from minor local variations the general pattern is similar to that produced by the colorimetric method (Fig. 19A); a general anomaly of tenor 15-20 p.p.m. Be is present over the pegmatite and there is a peak value of 70 p.p.m. Be over the beryl zone.

A gamma-neutron instrument survey was carried out along Traverses 150W (Fig. 19) and 250W (Fig. 20) by K. C. Burke who used the portable equipment described by Bowie et al. (1960) to obtain both surface and sub-surface readings. The general anomalous values are present over the pegmatite, with strong peaks above the beryl zones, although the main beryl zone is not distinguished in the surface readings of Traverse 250W (Fig. 20B). The essential factor by which these results differ from those of the other methods is the much higher tenor accompanied by greater fluctuations in values. This difference is due to the fact that whereas only the -190 micron fraction of the soil was used for the colorimetric and spectrographic determinations the total soil is utilised by the gamma-neutron instrument. The total soil includes the coarse fractions (+190 microns), some of which have

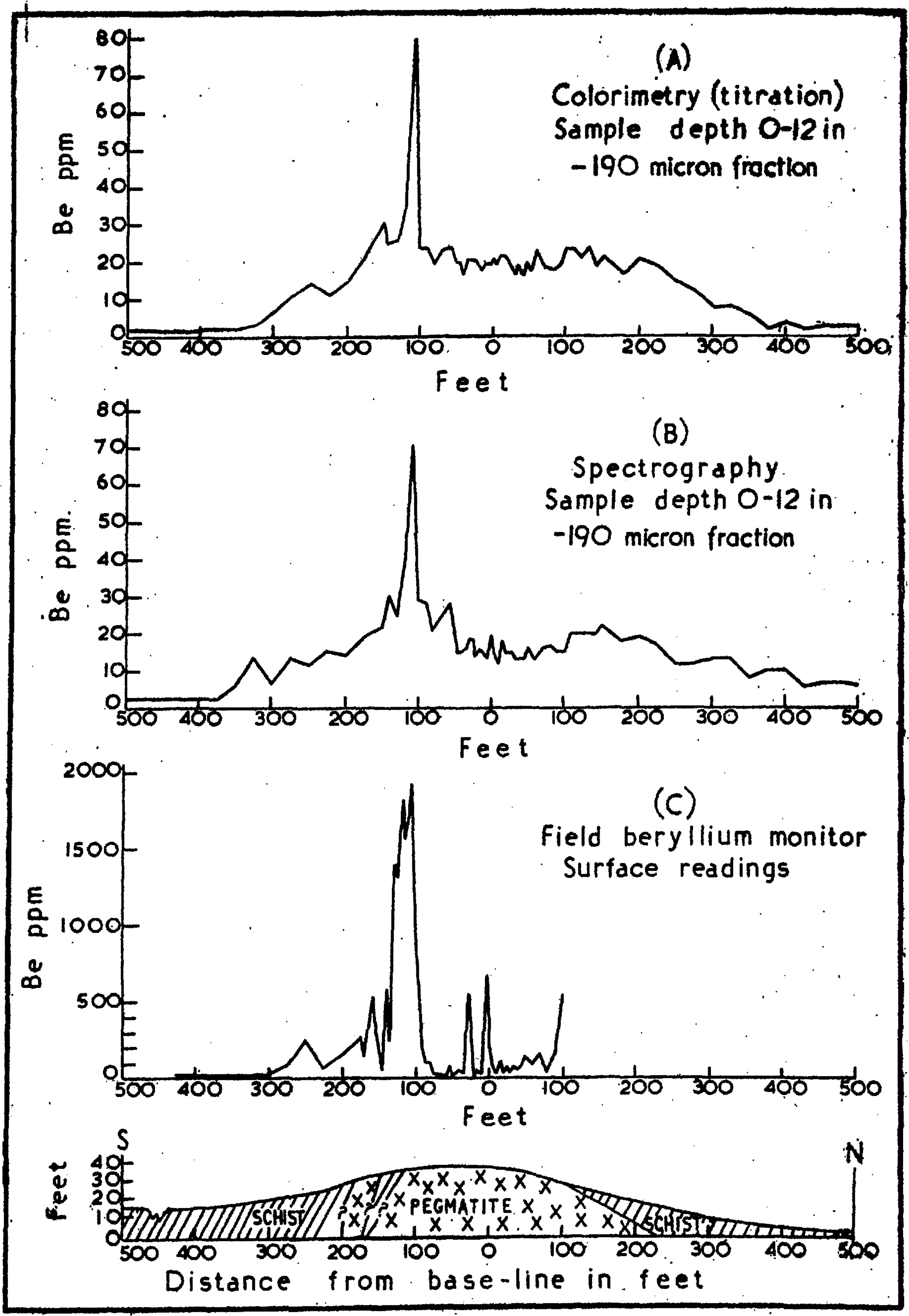


FIG.19. DISTRIBUTION OF Be IN SOILS, TRAVERSE 150W, BEPE 2.
[Samples dry-sieved]

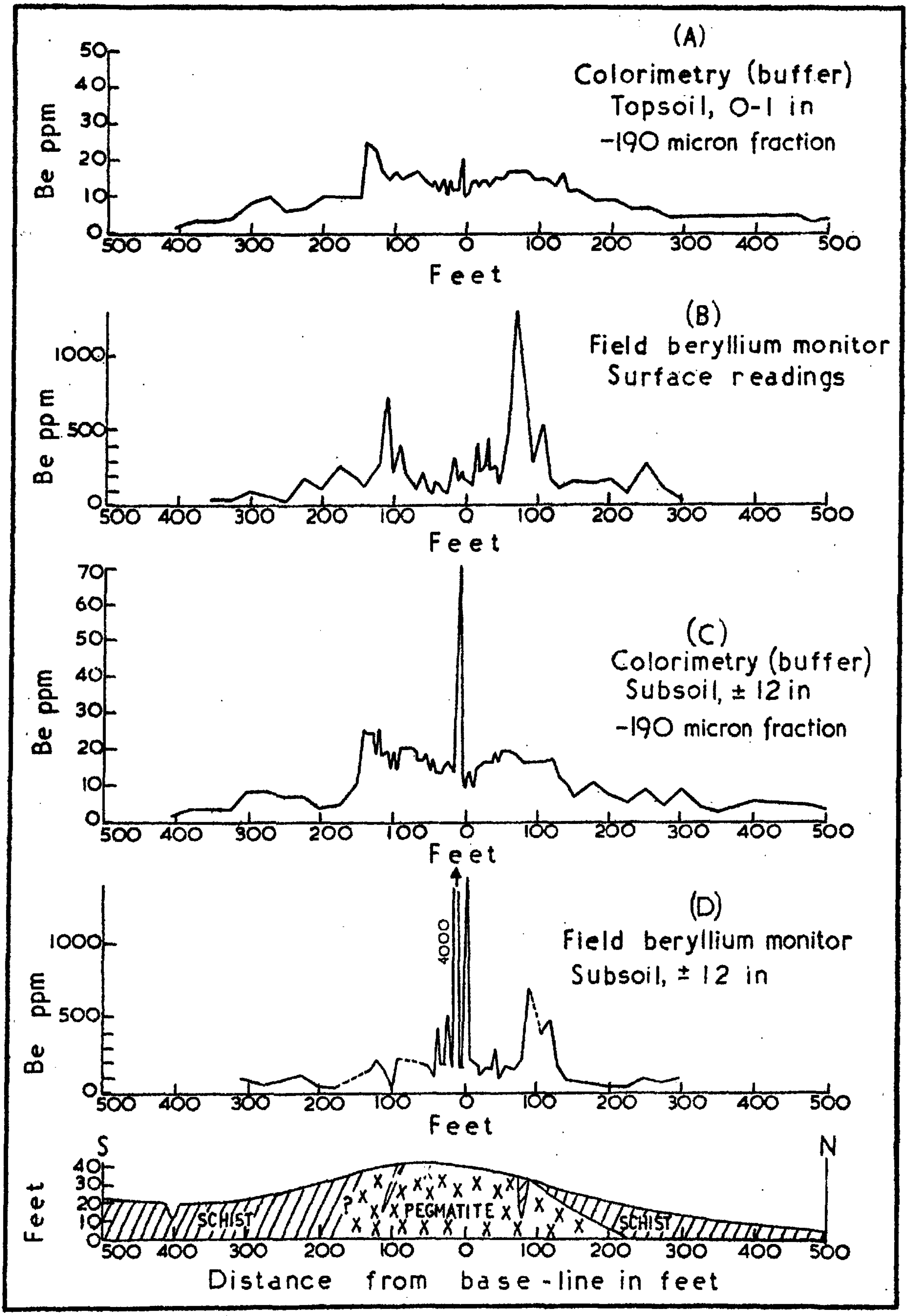


FIG. 20. DISTRIBUTION OF Be IN SOILS, TRAVERSE 250W, BEPE 2.
[Samples dry-sieved]

been shown in Fig. 11 to be of considerably higher tenor than the fine fractions. The marked fluctuations in instrument values reflect the uneven distribution of coarse beryl fragments within the soil. Chemical analyses of total soil samples would probably produce values equivalent to those given by the field instrument, but, as shown earlier, it would be necessary to crush samples weighing several kilograms before analysing them.

(vii) Results for other elements

The -190 micron fractions of soils from Traverse 150W were analysed spectrographically for a number of other elements by J. D. Kerbyson (Fig. 21). The results are described in a report by Kerbyson and Webb (1959) who summarize the principal features as follows:

(a) Li, Rb, Ba, Sr and Sn show positive anomalies of comparable widths related to the pegmatite;

(b) Ni, Co, Cr, V and Cu show "negative" anomalies, or troughs over the dyke. The higher values on either side are almost certainly related to the basic nature of the schist country rock;

(c) Mn, Pb and Ga show little tendency to vary in a manner that can be related to the geology, although there is, perhaps, slight evidence that Mn decreases over the dyke, as might be expected;

(d) There is little difference in the contrast between anomalous and background values for Li and Be (c.f. Karaeva and Chesnokov (1958) who consider that Li may be a suitable

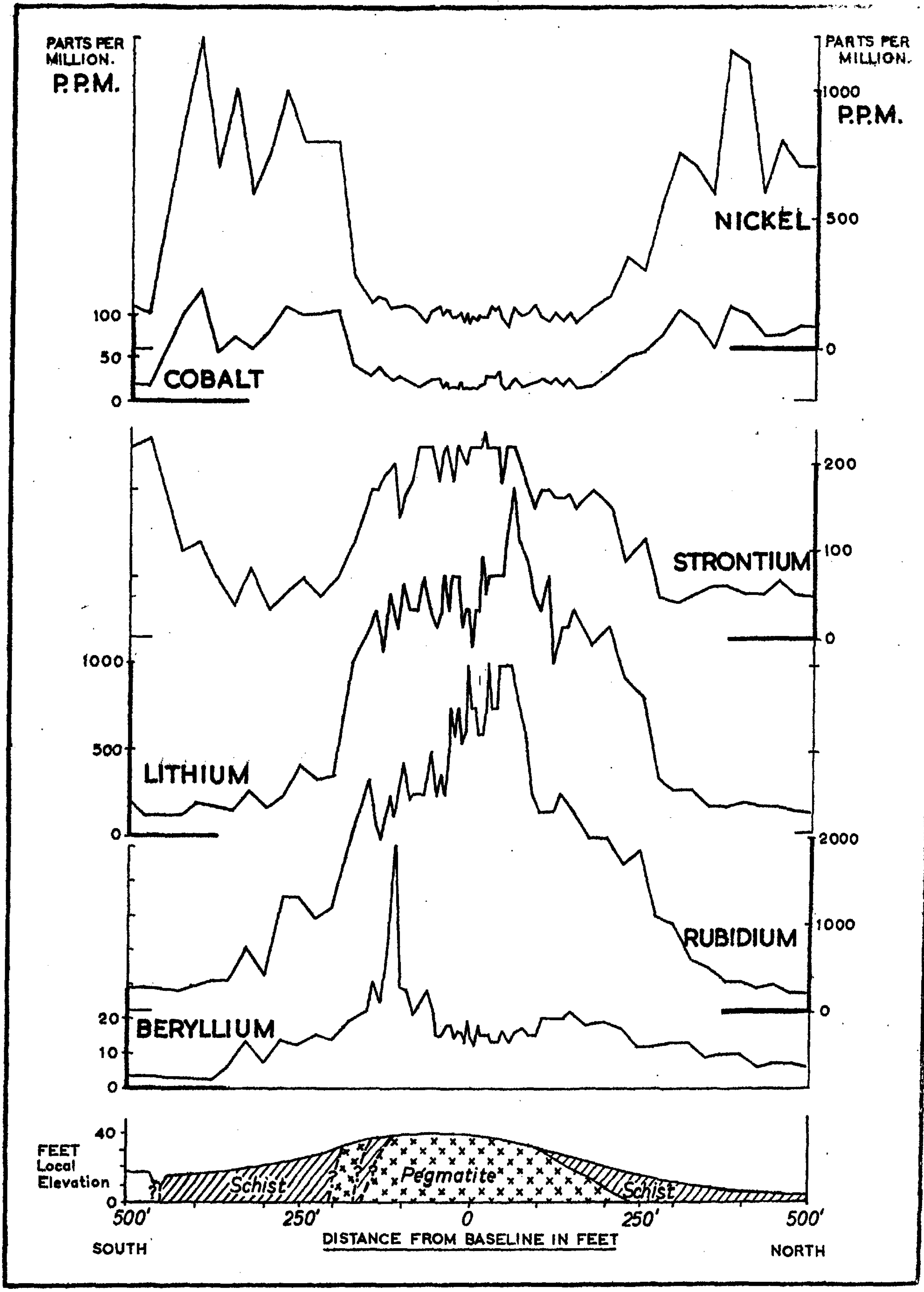


FIG. 21. MINOR ELEMENTS IN SOILS, TRAVERSE 150 W, BEPE 2.

indicator element for Be). The contrast for Rb is rather greater, however, while that for Ba, Sr and Sn is distinctly less;

(e) At the southern end of the traverse beyond the stream, Ba and Sr show a marked rise (Ba to almost double the peak values over the pegmatite and Sr to values similar to those over the pegmatite), while Li, Rb, Be and Sn tend to remain at the local background level, and Cr, V, Cu, Co and Ni values decrease. These variations, originally interpreted by Kerbyson and Webb as reflecting a change in lithology of the country rock and not to the presence of a second mineralised pegmatite, are now known to be due to sericitised quartzite.

(viii) Base-exchange capacity of clay and exchangeable-Be

The possibility of the Be in the clay-fraction being in exchange positions was investigated by

(a) determining the base-exchange capacities of several clay samples from Bepe 2 soils by the method detailed in Appendix I; and

(b) analysing the leachates for Be to obtain the exchangeable-Be content of the clay-size fraction.

The results are given in Table 20.

The significant difference between the base-exchange capacity of clay from soil over pegmatite and that of clay from soil over schist is that the former is in general twice the value of the latter. The amount of exchangeable-Be present in the samples is too small to permit the drawing of any conclusions regarding the correlation of exchangeable-Be with base-exchange capacity at the prevailing pH of 6-7.

TABLE 20

Exchangeable-Be and base-exchange capacity of clay, Bepe 2

Profile	Depth (in.)	Horizon	Weight per cent of clay-fraction	Base exchange capacity (meq/ 100 g)	Exchange-able-Be (p.p.m.)	Total Be (p.p.m.)
109S pegmatite- beryl zone	0-6	Topsoil	12.4	14.7	n.d.	8
	6-12	Subsoil	12.4	11.5	n.d.	8
	12-20	"	11.2	12.5	0.1	15
10N pegmatite- felspar zone	0-5	Topsoil	12.0	11.0	n.d.	3
	5-10	"	13.5	9.8	n.d.	10
300S schist down- slope from pegmatite	13-26	Subsoil	33.4	4.2	n.d.	5
2000S background schist	0-12	Topsoil	33.4	6.0	n.d.	0.5

n.d. = not detected; less than 0.05 p.p.m.

3. Vegetation

In common with most elements Be is known to occur in vegetation although insufficient data is available to enable the normal amounts of the element in plants to be established. However, Zalashkova et al. (1958) have demonstrated that in beryl-pegmatite areas in Russia, vegetation growing over Be-bearing pegmatites contains up to 39 p.p.m. Be in the ash compared to 3 p.p.m. or less in similar species growing in barren areas.

In the present investigation samples of leaves and twigs of two common tree species growing in anomalous and background soils were collected, ashed and analysed for Be. The results (Table 21) show a low general level of values with only a slight tendency to be higher over the beryl zone. In view of the discouraging results, no further study of the biogeochemical method was undertaken in the Bepe area.

TABLE 21

Be in plant ash, Bepe 2

Sample position	Species	Material	per cent ash	p.p.m. Be	
				Plant ash	Soil (-190 micron fraction)
Near beryl zone of pegmatite					
120S. 150W	Terminalia sericea*	twigs	6.4	2.0	30
110S. 150W	"	"	3.4	2.0	80
"	Brachystegia boehmii**	"	6.5	1.5	80
Background					
2000S	Terminalia sericea	leaves	9.4	1.5	1
"	"	twigs	7.6	1.0	1
"	Brachystegia boehmii	"	6.9	1.0	1

* Terminalia sericea is locally known as mususu.

** Brachystegia boehmii is locally known as mupfuti.

4. Stream Sediments

Extensive surface-drainage sampling was not undertaken at Bepe 2 due to the possibility of contamination from the Lucky Bean opencast workings at the western end of the Bepe 2 dyke where it is crossed by the only major stream in the vicinity.

A few -190 micron sediment samples were collected, however, during the course of routine soil sampling. The results are shown in Fig. 22A, together with those for the 80-190 micron fraction.

The 80-190 micron material gives a noticeably greater anomaly contrast than the -190 micron fraction. This is not due to higher anomalous values but rather to the lower background content which is a result of the concentration of Be in the fine fraction of soil derived from the sericitic quartzite.

Contamination from the opencast could be responsible for the high contrasts of 30-fold detected in the main stream. It is interesting to note, however, that the high values diminish rapidly and are almost undetectable at distances greater than 1500 feet from the pegmatite. This rapid dilution of Be in the -190 micron fraction is possibly due to additions of fine material eroded from background schist soils and a similar dilution may not occur in the coarse fractions to which very little background material is added.

A weak Be anomaly is also present in sediments of the tributary stream which passes to the south of the Bepe 2 dyke. It is possible that samples of coarse material (190-2000 microns) would have produced a more pronounced anomaly in this stream.

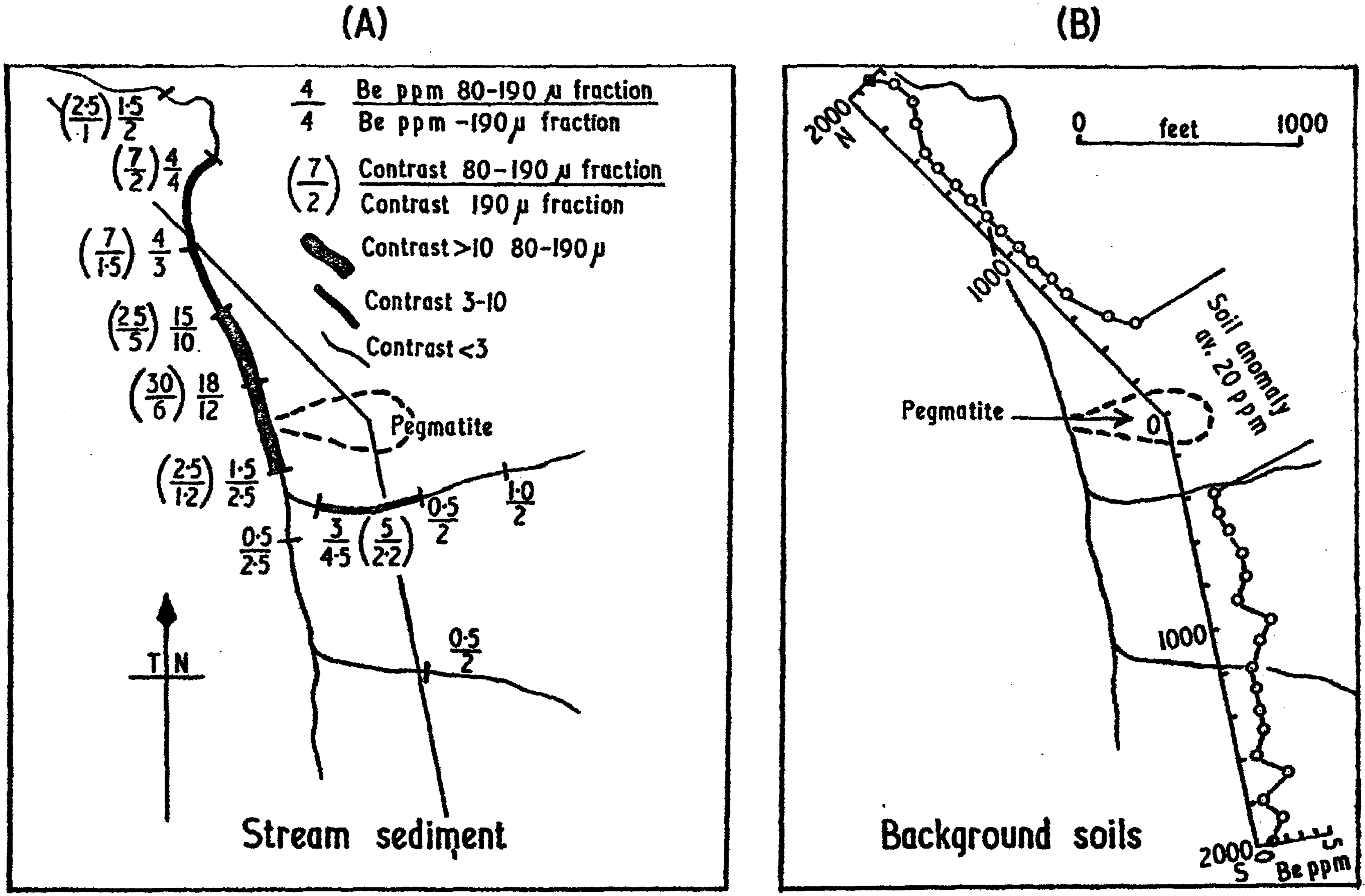


FIG. 22. Be IN (A) STREAM SEDIMENTS AND (B) SOILS, BEPE 2.
[Samples dry-sieved]

C. Beryllium Distribution at the Bepe 4 Pegmatite

Limited soil sampling was carried out in the vicinity of the Bepe 4 dyke in order to establish whether or not the dispersion pattern was similar to that observed at Bepe 2.

The location of the Bepe 4 dyke, which is U-shaped in plan, is shown in Fig. 7. The pegmatite is genetically similar to the Bepe 2 dyke (i.e. belongs to the same group in the Beus classification, see p. 38). The beryl zone, associated with the quartz core, is located in the northern projection. Unlike the Bepe 2 pegmatite, which forms a minor feature in almost flat terrain, the Bepe 4 dyke occurs on a low ridge sloping down from a hill of banded ironstone to the south. Dispersion of beryl downslope from the pegmatite can occur in all directions from east through north to west but not to the south. A north-south section showing topography and inferred geology is given at the bottom of Fig. 23. Also shown in the figure is a plot of the Be values of the -190 micron fraction of soil samples collected from Traverse 0 which crosses the dyke from south to north.

Background values on Traverse 0 over schist bedrock upslope from the pegmatite lie in the normal range of 1-2 p.p.m. Be. Banded-ironstone and granite background values are 2 and 4 p.p.m. Be respectively (-190 micron fraction of soils). A diffuse anomaly with values of the order of 10 p.p.m. Be is located over the pegmatite and extends 150 feet downslope from the dyke; there is a narrow peak with a value of 100 p.p.m. Be

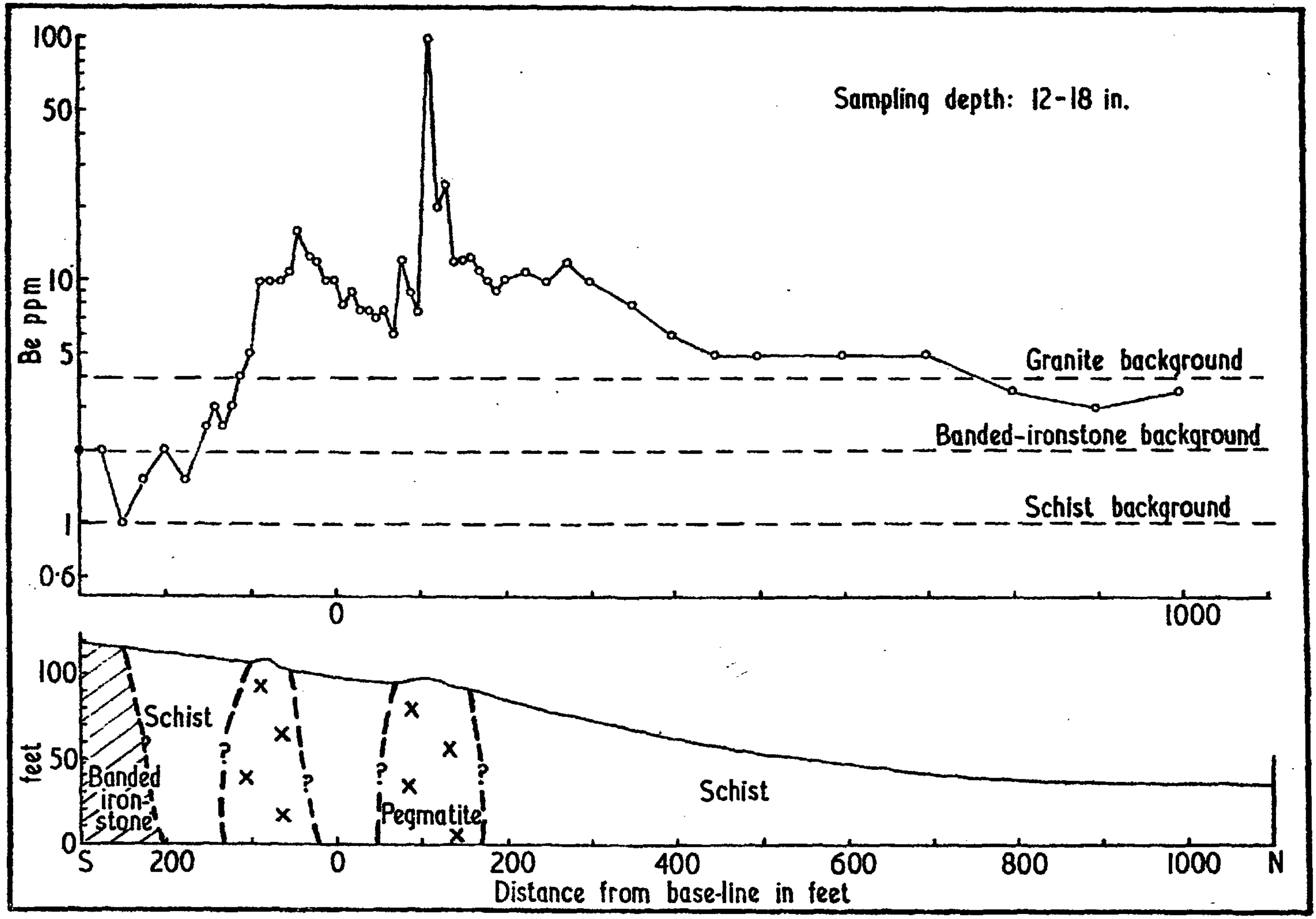


FIG. 23. DISTRIBUTION OF Be IN SOIL (-190 micron fraction), BEPE 4.
[Samples dry-sieved]

over the beryl zone. The anomaly decreases gradually in tenor as the distance from the dyke increases, although values of 4-5 p.p.m. Be persist to the end of the traverse, 850 feet from the dyke. It is possible that beyond 650 feet from the pegmatite the soil values are influenced by admixture with material moving downslope from the west, derived from granite bedrock which outcrops some 200-300 feet away. These granite soils have a content of approximately 4 p.p.m. Be in the -190 micron fraction and they may be responsible for maintaining the 4-5 p.p.m. Be level observed over the schist at the north end of Traverse O.

Samples A, B, C and D from four positions along Traverse O (Fig. 24) were separated into size-fractions by the sedimentation method (Table 22); the -20 micron fraction was not, in this case, separated into the silt and clay components.

TABLE 22

Mechanical composition of soil samples, Bepe 4

Sample No.	Distance from pegmatite (feet)	Fraction (microns)						
		900-2000	470-900	190-470	100-190	80-100	20-80 (fine sand)	-20 (silt and clay)
		Weight per cent						
A	0	13.3	7.1	5.7	10.0	8.2	19.0	36.7
B	125	6.4	2.4	4.3	10.2	7.5	30.4	38.8
C	300	1.7	2.1	5.8	9.7	8.6	31.4	40.7
D	900	3.9	1.6	4.7	11.3	10.5	24.7	43.3

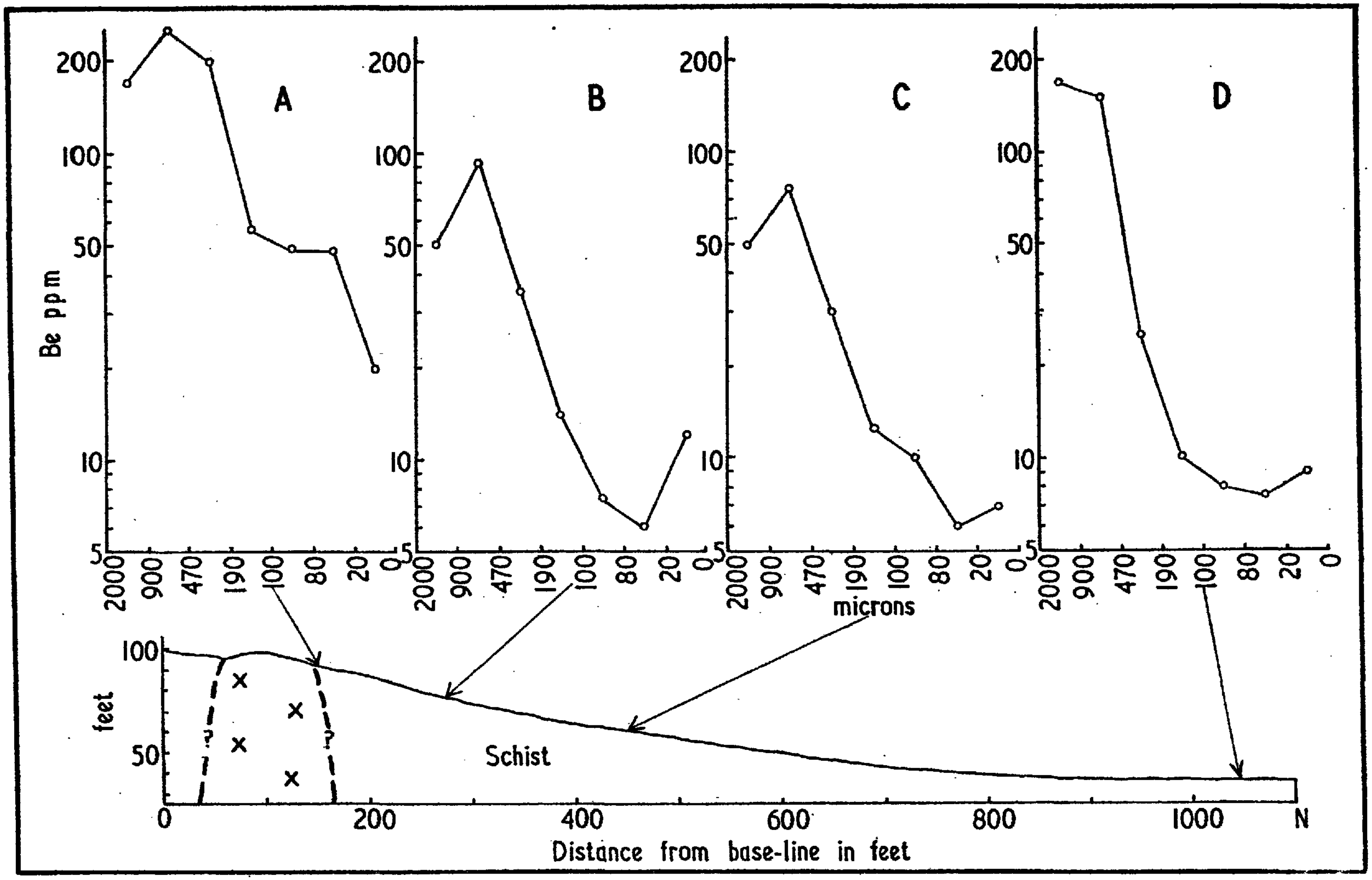


FIG. 24. Be DISTRIBUTION IN DIFFERENT SIZE-FRACTIONS OF SOILS, BEPE 4.
(Samples collected by J.S.Webb)
[Samples treated by sedimentation]

The patterns of Be distribution in the size-fractions are essentially similar to those for the anomalous Bepe 2 samples, i.e. there is a progressive decrease in Be content with particle-size from the 470-900 micron fraction down to the finest material (Fig. 24); the slight increases in the -20 micron fraction are insignificant. At Bepe 4, however, the 900-2000 micron fraction value tends to be lower than that of the 470-900 micron material. This is probably due to poor representivity in the coarse fraction, although it is possible that the bedrock pegmatite may contain fine-grained or finely-parted Be minerals.

The two main features evident from the Bepe 4 studies are:

(a) The persistence of high Be values in the coarse fractions at distances of at least 900 feet from the dyke (no other beryl pegmatites are known in the immediate vicinity to account for this persistence);

(b) Apparently anomalous values in the fine fractions of schist soils may be due to mixing with granite soils which characteristically contain high background values in the fine fractions.

D. Summary

1. The Bepe pegmatites belong to the group of fully-differentiated muscovite-microcline pegmatites in the Beus classification. In this group, the beryl is a coarsely-crystalline variety chiefly associated with the quartz core and replacement zones.

2. All the Be in the pegmatites is not concentrated in beryl. A certain percentage (usually about 5 per cent but occasionally as high as 50 per cent) is dispersed throughout the main rock-forming minerals and other accessory minerals.

3. The primary dispersion of Be into the schist wallrocks enclosing the pegmatites is not extensive, the maximum observed width of the aureole being 12 feet.

4. The Be content of background soils depends upon the bedrock lithology. The -190 micron fraction of soils over schist contain 1 p.p.m. Be, over granite and sericitic quartzite the values are up to 4 p.p.m. and over banded ironstone and dolerite 2 p.p.m. In soils derived from granite and sericitic quartzite the Be tends to be concentrated in the finer fractions.

5. In the vicinity of the beryl-bearing dykes, the -190 micron fraction of soil contains anomalous amounts of Be ranging up to 10-100 p.p.m. The anomalous pattern is detectable for distances of 150 feet to perhaps 650 feet from the edge of the dyke, depending on the local topography.

6. Over the dyke itself, the distribution of peak values reflect zoning of Be in the underlying pegmatite.

7. All size-fractions of soils reveal Be anomalies over the pegmatites.

8. The highest Be contents occur in the coarsest fractions of anomalous soils and the values progressively decrease with

particle-size. This pattern of size-distribution persists for many hundreds of feet from the pegmatite indicating that the anomaly is largely due to mechanically dispersed beryl.

9. Analyses of coarser soil fractions give anomalies of greatest contrast; they also give anomalies of greater extent owing to the dilution of anomalous fine fractions by fine material derived from barren schists.

10. The clay-fraction from soils over the beryl zone contains very small amounts of Be in relation to the silt and coarser fractions.

11. Coarse fractions must be crushed to allow complete chemical attack if maximum and representative values are required. Fractions finer than 190 microns do not require crushing.

12. Representivity in coarsest fractions is very poor unless extremely large samples are ground before analysis. The amount of sample required to achieve representivity decreases rapidly with decrease in particle-size or increase in Be content. Sampling precision becomes less than the analytical variation for fractions finer than 190-470 microns, and in this size-range representivity is achieved by taking only 2.5 g.

13. A sample of the -190 micron fraction of a soil collected at one point is reasonably representative of this fraction of the soil within at least 25 feet of the sample point, provided that there is no beryl zone in the vicinity.

14. Spectrographic and field gamma-neutron instrumental methods produce anomaly patterns similar to those of the colorimetric method. The field instrument is extremely sensitive to coarse beryl fragments in the soil and as a consequence values fluctuate markedly within the anomaly.

15. No other element is sufficiently closely related to Be to permit its use in prospecting surveys for beryl.

16. Very little of the Be in the clay fraction is present in exchange positions on the surfaces of clay minerals.

17. Beryllium does not appear to be associated with organic matter.

18. Very little Be appears to be taken up by the two common species of trees examined and the observed differences in the Be content between plants growing over the pegmatite and over background schist were too small to constitute a readily detectable anomaly, at least by the methods employed.

19. Only limited data on the Be content of stream sediments was obtained. Contrasts as high as 30 were given by the 80-190 micron fraction of possibly contaminated sediments but the anomalous values persist for less than 1500 feet from their source. The magnitude and persistence of anomalous values in the -190 micron material are less than in the case of the 80-190 micron fraction.

2. MISTRESS CLAIMS AREA, SOUTHERN RHODESIA

A. Description

Physical features: The Mistress Claims are situated in hilly country 14 miles north of Salisbury at a latitude of 17°37'S and a longitude of 31°06'E (Fig. 6).

The climate and vegetation are similar to that in the Bepe area although the summer mean temperatures are a little lower due to the greater altitude of 4,800 feet. The mean annual precipitation is also rather higher at 35 ins.

The pegmatite occurs along the top of one of a series of prominent ridges which are elongated in a south-east to north-west direction and which control the local drainage. The main stream draining the area, the Mabfeni River (Fig. 29), is perennial although it barely maintains a flow at the end of the dry season. The tributary streams, including those draining the Mistress dyke, are dry for most of the year. The Mabfeni River flows into the Mazoe River which eventually joins the Zambezi River in Portuguese East Africa.

Geology: The plateau which lies between the Mistress area and Salisbury is composed of Pre-Cambrian schists. The Mistress Claims are located at the contact between these schists and granite gneiss, both belonging to the Basement Complex. The pegmatite occurs within the gneiss.

The local geology (Fig. 25) has been described by Gallagher (1959). The main pegmatite, which has been worked in its central section by open-casting, is steeply dipping, 100-120 feet in width and 3000 feet in length along the north-west to south-east strike. Unlike the massive pegmatite in the north-western portion, the

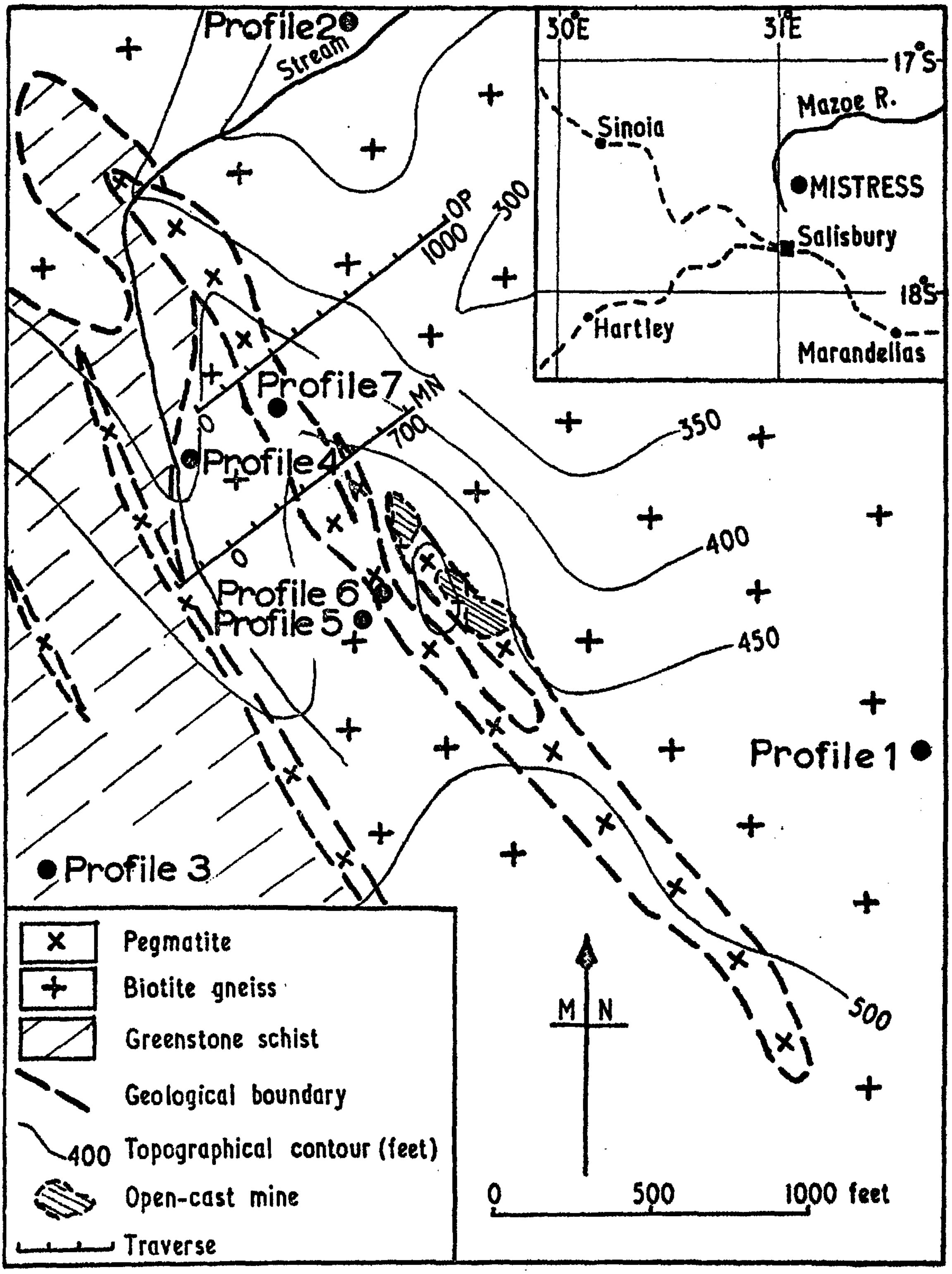


FIG. 25. GEOLOGY AND TOPOGRAPHY OF THE MISTRESS AREA (after U.K.A.E.A. Salisbury Office)

south-eastern section is composed of a number of thin pegmatite fingers. The chief country-rock is a massive hornblende-biotite gneiss which is medium- to coarse-grained and roughly foliated; large inclusions of this material occur centrally within the pegmatite. Greestone schist is in contact with the north-western end of the pegmatite and is the main rock-type further to the west. Smaller pegmatites, which in places contain beryl, occur to the west and trend sub-parallel to the main dyke.

The Mistress pegmatite belongs to the group of replaced lepidolite-albite pegmatites in the paragenetic zonal classification proposed by Beus (1956a). According to Gallagher (1959), the composition of the dyke is as follows:

Zone	Description	Width
Contact zone	Sodium felspar, potassium felspar, quartz and muscovite with a generally medium-grained (1 in. average grain-size) texture. Usually constitutes about ⅔rds total width of the dyke.	Varies considerably average 70 feet
Outer intermediate zone	Sodium felspar (albite), potassium felspar and quartz.	20 feet
Intermediate zone	Spodumene-quartz units occurring locally.	10 feet

Zone	Description	Width
Inner Intermediate zone	Fine-grained lepidolite assemblage.	10 feet
Core	Massive quartz, lensing.	15 feet

Beryl occurs mainly in the contact and outer-intermediate zones, mostly in the form of small greenish-white prisms which are a high-alkali variety with Cs and Rb as important minor constituents. Minerals extracted from the pegmatite in addition to beryl are lepidolite, spodumene, microlite and tantalite (Gallagher, 1959).

Overburden: As at Bepe 2 the overburden is dominantly residual with poorly developed soil horizons particularly over the pegmatite where slopes are steep and only thin soil cover is found. Soil profiles typical of those developed over pegmatite and gneiss are described below.

Soil Profile Developed over Pegmatite at Mistress

Depth. (ins)	Horizon	Colour and Texture	pH
0-5	Topsoil	Grey-brown sandy loam with some felspar and quartz gravel up to 1 in. in size.	6.2
5-21	Subsoil	Light reddish-brown gravel of felspar and quartz with some loamy sand,	6.0
21+	Weathered pegmatite, soft brown to hard white material.		

Soil Profile Developed over Gneiss at Mistress

Depth, (ins)	Horizon	Colour and Texture
0-5	Topsoil	Grey (at top) to brown (at bottom) sandy-loam with a little quartz and felspar gravel material.
5-27	Subsoil	Brown loamy sand decreasing in amount on passing down the profile with a corresponding increase in the amount and size of felspar and quartz gravel fragments.
27+	Weathered gneiss, mottled white, brown and black.	

The grey coloration of the topsoil is probably due to a small amount of organic matter combined, perhaps, with some leaching of sesquioxides into the lower horizons. Except on the ridge crests, much of the topsoil material is possibly derived from upslope by soil creep.

B. Beryllium Distribution at the Mistress Pegmatite

1. Pegmatite minerals

The Be contents of the common rock forming minerals in the Mistress dyke are less than those of the Bepe 2 minerals, viz:

Mineral	Mistress dyke Chemical value (p.p.m.)	Mistress dyke Gamma-neutron assay (p.p.m.) (Gallagher, 1959)	Bepe 2 dyke Chemical value (p.p.m.)
Quartz	0.5	-	0.5-1.0
Microcline	1.0	less than 7	1.5-3
Muscovite	8	less than 7	13-60
Lepidolite	-	7-35	-

2. Soils

(i) Background and threshold values

There is very little variation in the distribution of Be in the -190 micron fraction of soil in profiles developed over gneiss and schist (Table 23).

TABLE 23

Be content of soils from background profiles in the Mistress Claims area

Material	Soil over gneiss				Soil over schist	
	Profile 1		Profile 2		Profile 3	
	Depth (ins)	p.p.m. Be	Depth (ins)	p.p.m. Be	Depth (ins)	p.p.m. Be
Topsoil	0-1	2	0-5	2	0-6	3
	1-3	2	5-15	2	6-15	2.5
	3-7	2.5	15-27	2	15-27	2
Subsoil	7-13	3	27+	2.5	27+	1.5
	13-24	2				
	24-34	2.5				
Weathered bedrock	34-36	2.5				

Profile 1 and profile 3 samples dry-sieved, profile 2 samples treated by sedimentation.

Additional background data was obtained from the north-eastern limits of Traverse OP (Fig. 25) where it passed over background gneiss bedrock. Between 500 and 700 feet from the dyke the Be values of the -190 micron fraction of subsoils were 1-2 p.p.m.

On the basis of the above data 2.5 ± 0.5 p.p.m. Be is taken as the general background value for the -190 micron fraction of both the gneiss and schist soils. The threshold (upper limit of background fluctuation) is 3 p.p.m. Be.

The mechanical composition of a subsoil sample (5-15 in.) from Profile 2 is given in Table 24. The analysis of the different size-fractions (Fig. 26) shows that maximum Be values occur in the finest fractions. A corresponding trend was noted in the background granite soil at Bepe (Table 7).

TABLE 24

Mechanical composition of subsoil samples, Mistress Claims area

Bedrock	Fraction (microns)							
	900-2000	470-900	190-470	100-190	80-100	20-80	2-20 (silt)	0-2 (clay)
	Weight per cent							
Pegmatite (Profile 7; 5-21 in.)	11.0	9.2	16.2	15.1	6.3	17.8	12.9	11.5
Gneiss (Profile 2; 5-15 in.)	6.6	8.9	14.8	11.0	5.9	18.0	13.9	20.9

Samples treated by sedimentation

(ii) Distribution of Be in anomalous profiles

The data for the -190 micron fraction of soil from anomalous profiles (Table 25) show that, apart from the bedrock samples, values are reasonably consistent throughout the soil profile

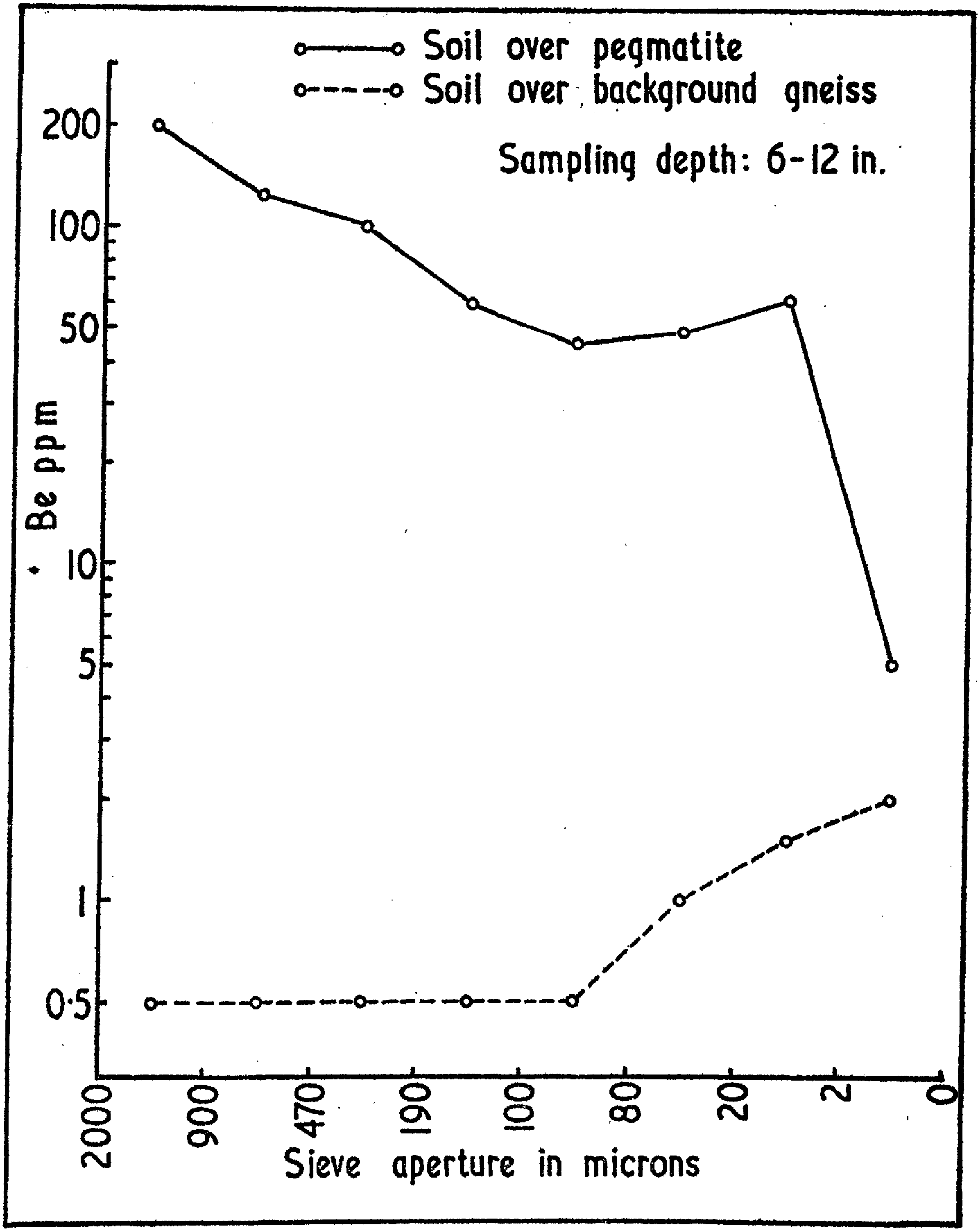


FIG. 26. Be DISTRIBUTION IN SIZE-FRACTIONS OF SOILS, MISTRESS CLAIMS.
[Samples treated by sedimentation]

TABLE 25

Distribution of Be in anomalous soil profiles, Mistress Claims area, (data refer to -190 micron fraction)

Material	Profile 4 Soil over schist bedrock, 350 feet downslope from pegmatite		Profile 5 Pegmatite rubble over gneiss bedrock, 20 feet downslope from contact		Profile 6 Pegmatite contact zone		Profile 7 Pegmatite, outer-intermediate zone	
	Depth (ins.)	p.p.m. Be	Depth (ins.)	p.p.m. Be	Depth (ins.)	p.p.m. Be	Depth (ins.)	p.p.m. Be
Topsoil	0-2	10	0-2	9	0-2	16	0-5	100
	2-5	11	2-5	12	2-7	13	5-21	130
	5-10	15	5-10	13	7-18	13	21+	170
Subsoil	10-22	13	10-18	12	18-30	29		
	22-31	7	18-27	10	30-42	19		
	31-40	5	27-32	8	42+	6		
Weathered bedrock	40+	2.5	32+	3				

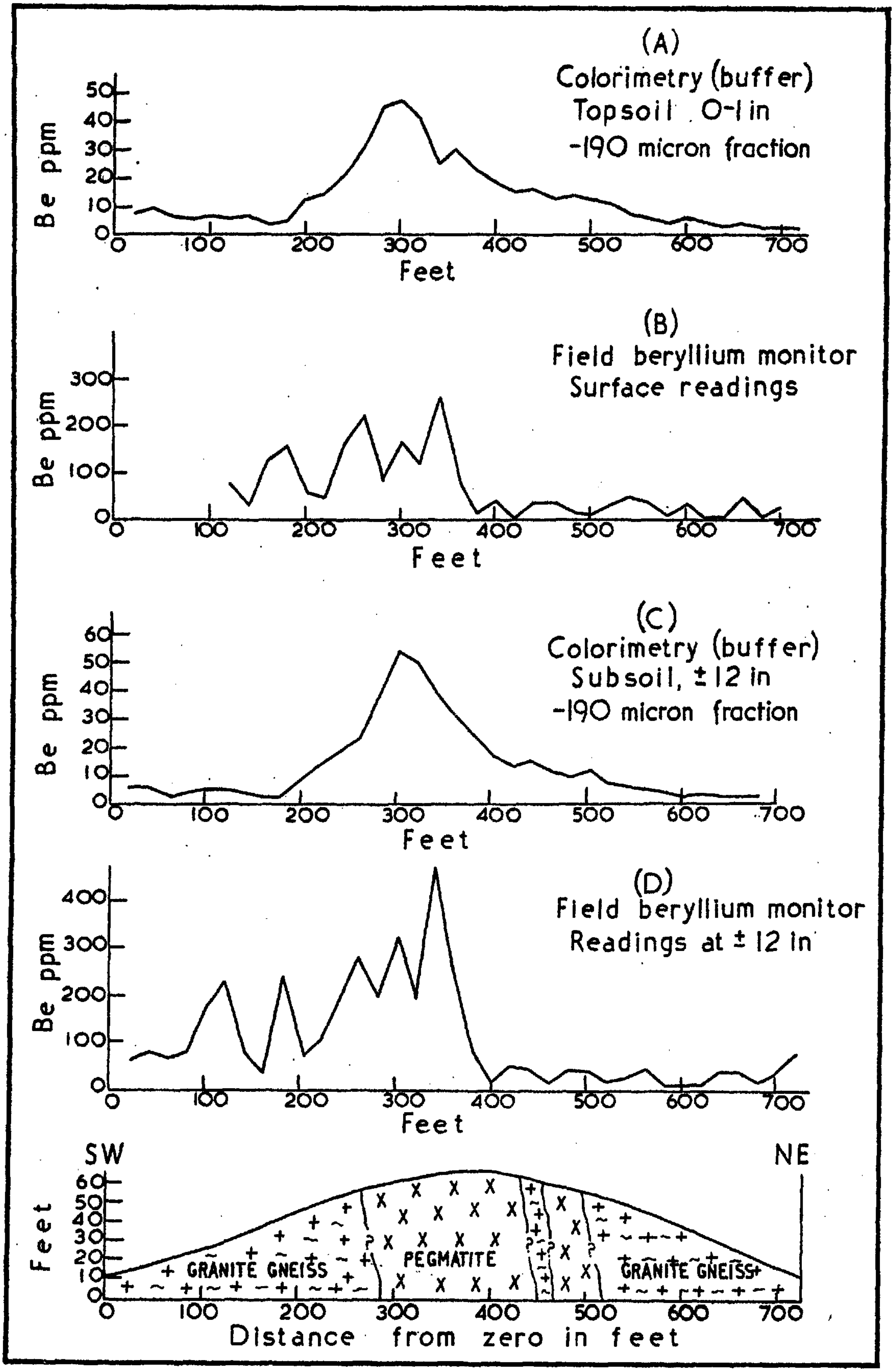
Samples dry-sieved, uncrushed.

over the pegmatite, and that downslope the anomalous Be contents in soil over gneiss and schist bedrock are, of course, derived from the pegmatite.

The mechanical composition of the subsoil (5-21 in.) sample of Profile 7 is given in Table 24. Analysis of different size-fractions shows that the Be content tends to decrease with decreasing particle-size in the soil derived from pegmatite (Fig. 26). This trend is particularly marked between the silt and clay fractions. The rate of decrease in values is much less marked than in the anomalous soils at Bepe 2 (Fig. 11).

(iii) Lateral dispersion of Be in soil

The lateral dispersion of anomalous Be in the -190 micron fraction of the soil downslope from the dyke along Traverse MN (Fig. 27) extends 100-150 feet from the pegmatite-gneiss contact. Peak values of 50 p.p.m. in both topsoil and subsoil occur over the main beryl-bearing zone (i.e. the outer-intermediate zone) which possibly is situated on the south-western side of the ridge where it is crossed by the traverse. The values on the north-eastern side are probably associated with the wide contact zone. On either side of the ridge the anomaly decays rapidly to background Be contents, with the dispersion in the topsoil being rather more extensive than that in the subsoil.



(A) Colorimetry (buffer) Topsoil 0-1 in -190 micron fraction

(B) Field beryllium monitor Surface readings

(C) Colorimetry (buffer) Subsoil, ± 12 in -190 micron fraction

(D) Field beryllium monitor Readings at ± 12 in

FIG. 27. DISTRIBUTION OF Be IN SOIL, TRAVERSE MN, MISTRESS CLAIMS.

[Samples dry-sieved]

The anomaly peak over the Mistress dyke is more diffuse than the sharp peaks observed above the Bepe pegmatites. This may be due to a combination of a broader beryl zone and to more active soil creep on the steeper slopes.

In view of the higher Be content of the coarse fractions of anomalous soils (Fig. 26) and the greater dispersion of Be in these fractions at Bepe 4 (Fig. 24) it is possible that analysis of the coarse fraction of the Mistress soils would reveal a wider anomaly than does the fine fraction. It would be necessary, however, to undertake the tedious crushing of large samples in order to achieve this.

(iv) Results achieved with alternative analytical method

The results obtained by K. C. Burke, using the portable gamma-neutron instrument to assess the Be anomaly along Traverse MN, are given in Fig. 27. The surface readings are generally less than those obtained at a depth of ±12 inches. In each case the anomalies coincide with those given by the chemical methods although there are marked fluctuations in the instrument readings down the south-western slope of the ridge indicating the presence of coarse beryl fragments in the soil. The tenor of the values for the total soil indicated by the gamma-neutron instrument are, in general, up to 8 times that given by the chemical method for the -190 micron fraction.

The width of the instrument anomaly is difficult to determine due to the fluctuations in values and the absence of background and threshold data.

3. Vegetation

Leaves and twigs of *Terminalia sericea* and *Brachystegia boehmii* species growing over pegmatite and over background gneiss were ashed and analysed for Be. The results show no significant correlation between the Be contents of the vegetation and proximity to mineralization (Table 26).

TABLE 26

Be in plant ash, Mistress Claims

Sample position	Species	Material	per cent ash	p.p.m. Be Plant ash	p.p.m. Be Soil (-190 micron fraction)
On pegmatite at Profile 7	*Terminalia sericea*	Twigs	7.6	3.0	120
	Brachystegia boehmii	do	12.4	2.0	120
On gneiss at Profile 2	*Terminalia sericea*	Leaves	5.6	3.5	2
	do.	Twigs	7.7	1.5	2
	Brachystegia boehmii	Leaves	5.0	2.5	2
	do.	Twigs	10.4	1.0	2

4. Stream sediments

Stream sediment samples were collected at a number of points in the Mabfeni River and its tributaries, including those which drain the Mistress Claims (Fig. 29). The Mistress tributaries were dry when sampled.

(i) Background and threshold values

The background values obtained in the reconnaissance sediment sampling survey (Fig. 29) were within the range 1.0–1.5 p.p.m. Be for the -190 micron fraction. The threshold value is 1.5 p.p.m.

The mechanical composition of a background sediment sample (No. 5, from the Matiro River) is given in Table 27. The distribution pattern of Be within the size-fractions (Fig. 28) is similar to that in the background gneiss soil (Fig. 26), i.e. the highest Be values occur in the fine fractions with a maximum content in the clay-size material. The value for the -190 micron fraction of this sample is 2.0 p.p.m. Be, rather higher than the range of background contents given above for the reconnaissance survey. The inclusion of this value in the reconnaissance data would raise the threshold to 2.0 p.p.m. Be. However, only minor modifications would have to be made to the drainage pattern in Fig. 29.

(ii) Reconnaissance samples

The reconnaissance survey (Fig. 29), using the -190 micron fraction of the samples, indicated the presence of anomalous amounts of Be along the entire length of the Mabfeni River,

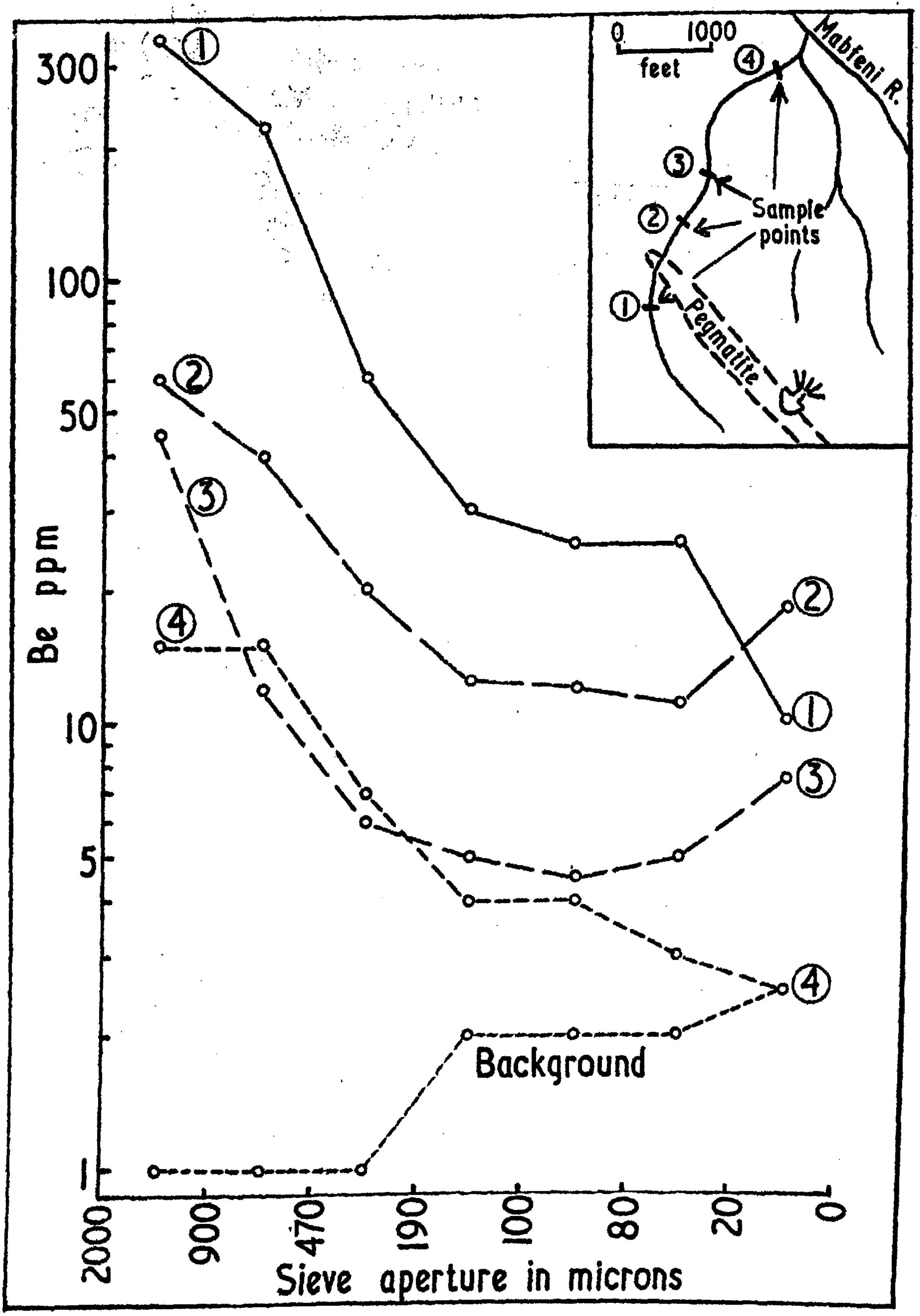


FIG. 28. Be DISTRIBUTION IN SIZE-FRACTIONS OF STREAM SEDIMENTS, MISTRESS AREA.
(Samples collected by K.C.Branscombe)
[Samples treated by sedimentation]

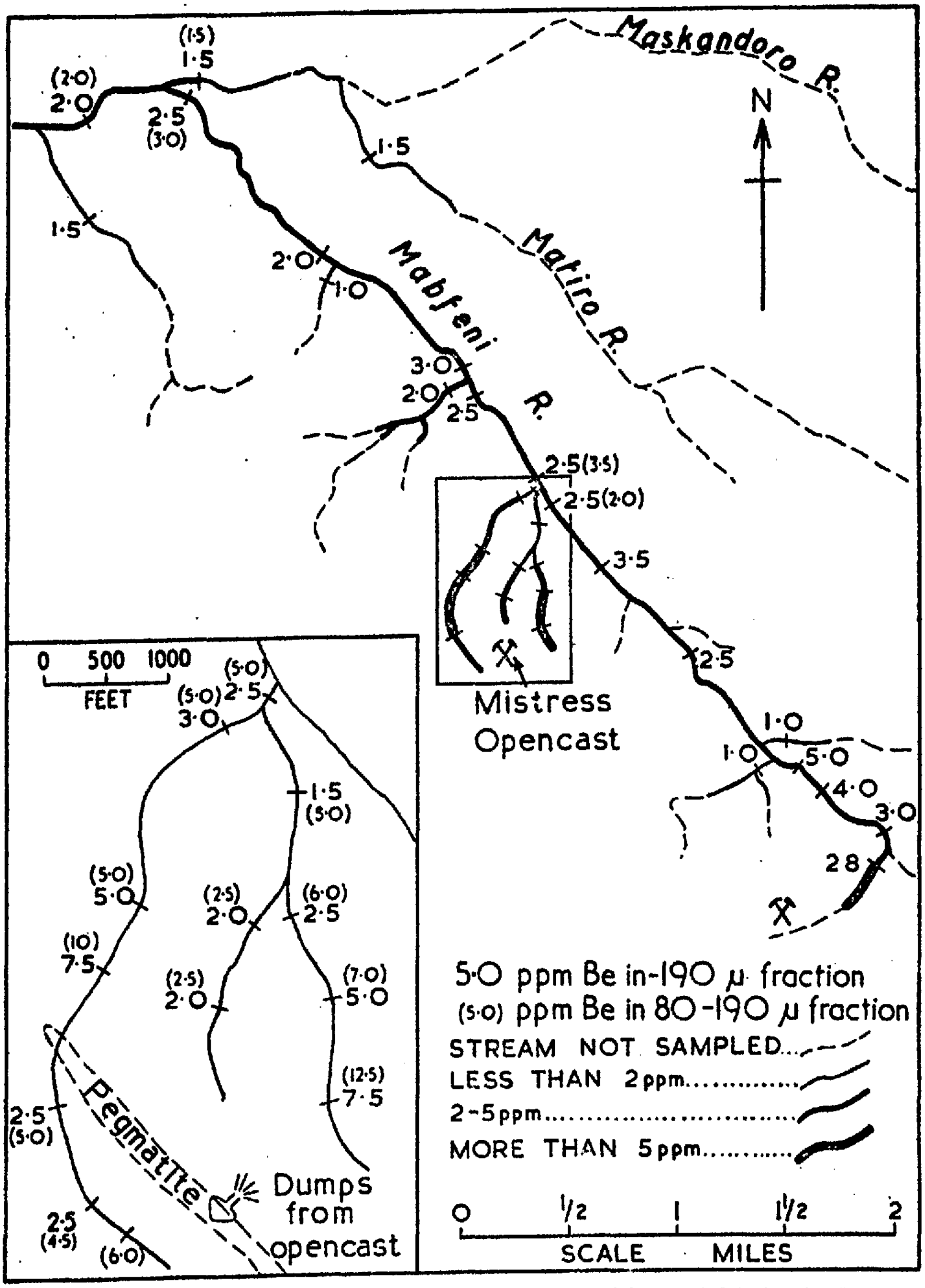


FIG. 29. DISTRIBUTION OF Be IN STREAM SEDIMENTS (-190 and 80-190 micron fractions), MISTRESS AREA. [Samples dry-sieved]

i.e. for 5 miles (this would be reduced to 3 miles with a threshold of 2 p.p.m. Be). In addition anomalous values were obtained in two tributaries. Muscovite, which possibly has a high Be content and which constitutes the greater proportion of the sample from the tributary near the river source, may be responsible for the value of 28 p.p.m. in this tributary. The other anomalous stream drains the Mistress pegmatite and more detailed sampling revealed that the anomalous material is most probably derived from this source (Fig. 29, Inset).

Testing of the 80-190 micron material improves both the absolute values and the contrasts of anomalous samples; the values are given in brackets in Fig. 29.

(iii) Distribution of Be in size-fractions of anomalous stream sediment

Four anomalous sediment samples were collected from the uncontaminated Mistress tributary (sample locations in Fig. 28, Inset) and separated into size-fractions by the sedimentation method. Their mechanical compositions are presented in Table 27.

TABLE 27

Mechanical composition of stream sediments, Mistress area

Sample No.	Fraction microns						
	900–2000	470–900	190–470	100–190	80–100	20–80	0–20 silt + clay
	Weight per cent						
1	3.3	10.0	15.0	14.2	9.0	18.5	30.0
2	9.1	9.8	9.7	11.3	6.4	20.5	33.4
3	11.3	11.8	8.7	12.1	6.4	18.6	31.2
4	12.6	24.6	21.2	11.3	4.4	13.1	12.8
5 (background)	19.4	21.5	10.1	9.8	4.4	13.4	21.4

In the upper reaches of the Mistress tributary the sediment is essentially valley-slope colluvium. This is reflected in the high percentage of silt + clay in samples 1, 2 and 3. The composition of sample 4 is more that of a true stream sediment.

In the anomalous sediment samples there is a general decrease in Be values with particle-size, although some minor variations occur in the fine fractions (Fig. 28). In this respect the results are similar to those obtained in the anomalous valley-slope soil (Fig. 26).

There is, in general, a progressive decrease in the Be content of each size-fraction on moving downstream, as emphasised in Table 28 wherein the results obtained on composite size-fractions are compared.

TABLE 28

Be values for size-fractions of stream sediments, Mistress area

Sample No.	Fraction, microns			
	190-2000	-190	80-190	-80
	p.p.m. Be			
1	150	20	28	16
2	40	14	12	15
3	22	6	5	7
4	12	3	4	3
5(background)	1	2	2	2

The highest Be values and the best contrasts with background are given by the 190-2000 micron fraction. At the confluence of the Mistress stream with the Mabfeni River (sample point 4, 3000 feet downstream from the dyke) the -190 micron fraction is barely anomalous, whereas high Be contents showing good contrast against background are apparent in the 190-2000 micron fraction.

C. Summary

1. The Mistress pegmatite belongs to the group of replaced lepidolite-albite pegmatites in the Beus classification. In this group the beryl is usually a high-alkali variety which does not occur in very large crystals (mostly less than $\frac{1}{2}$ in. diameter). In the Mistress pegmatite the beryl is associated with the contact and outer-intermediate zones.

2. Background values of 2-3 p.p.m. Be occur in the -190 micron fractions of soils developed over schist and gneiss. Stream sediment material of this size, derived from barren gneiss, contains 1.5-2 p.p.m. Be.

3. Analysis of size-fractions of soil and sediment derived from background gneiss indicate that Be is concentrated in the fine material, the highest values occurring in the clay-size fraction.

4. There is no significant correlation between soil horizon and the Be distribution in the -190 micron fraction of the anomalous overburden.

5. The anomaly peak of 50 p.p.m. Be (-190 micron fraction) is broader than that at Bepe 2, due to the greater width of the beryl-bearing zone and more effective movement by soil creep on the steeper slopes.

6. The lateral distribution of Be in this size-fraction extends no further than 200 feet from the pegmatite-gneiss contact; a wider dispersion probably exists in the 190-2000 micron fraction.

7. The highest Be values occur in the coarsest fraction of anomalous soils and stream sediments, and the contents progressively decrease with decrease in particle-size. In strongly anomalous samples the clay-fraction content is particularly low compared with the coarser fractions.

8. There is a progressive decrease in the anomalous Be content of most size-fractions of stream sediments on passing downstream from the pegmatite. The anomalous drainage train barely extends to a distance of 3000 feet from the dyke for the -190 micron fraction of stream sediment whereas it is at least 3000 feet, and possibly much greater, for the 190-2000 micron fraction.

9. The portable gamma-neutron instrument produces similar anomalous patterns over anomalous soils as does the chemical method, but values are higher and show greater fluctuations. As at Bepe 2 these differences are due to the fact that the instrument measures the Be content of the total soil whereas the chemical analyses refer only to the -190 micron fraction.

10. There appears to be no significant concentration of Be in the components of vegetation growing over the beryl pegmatite at the Mistress Claims.

3. ISHASHA AREA, UGANDA

A. Description

Physical features: The Ishasha area is situated in the Kigezi District of South West Uganda, near the border with the Belgian Congo (Fig. 30).

Although the area lies almost on the equator the climate is considerably modified by altitude. The temperature varies between 60°F and 80°F throughout the year. The mean annual rainfall of 76 inches is so distributed as to give two fairly

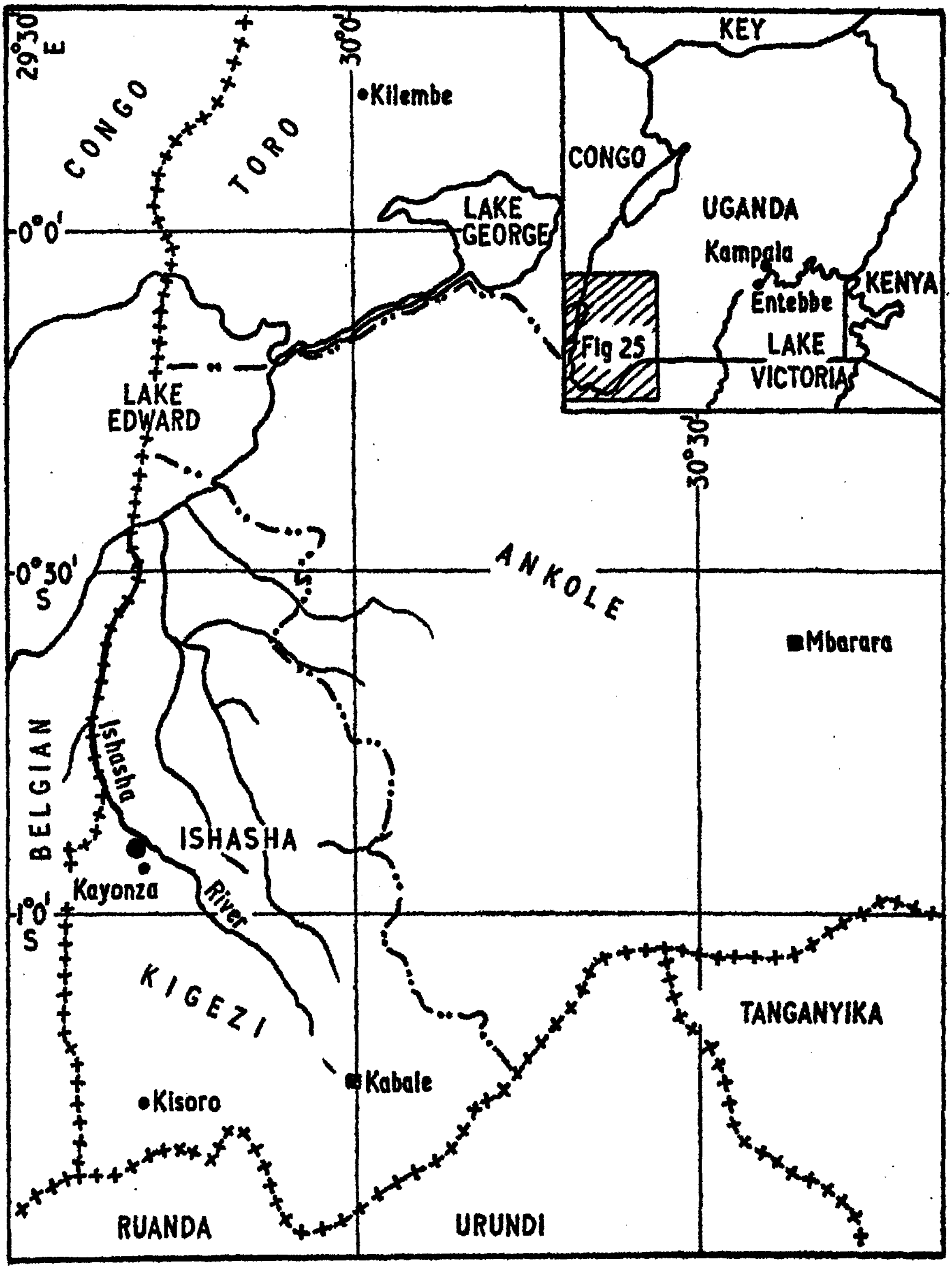


FIG. 30. LOCATION OF THE ISHASHA STUDY AREA.

well defined wet seasons, one from March to May and the other from September to November.

The predominant vegetation is dense tropical forest. In places on the steep hill-slopes the tall trees and thick tangled undergrowth have been cleared for native cultivation. The study area, however, is still covered by virgin forest.

The southern part of the Kigezi District is mountainous with many recorded heights over 8000 feet. It is an old plateau now deeply dissected by valleys running roughly parallel to the regional tectonic strike of 145°-160°. The Ishasha area is near the northern edge of the mountainous region; the highest hills are between 5000 and 5200 feet above sea-level. To the north the general elevation decreases rapidly to the flat country bordering Lake Edward which is 2995 feet above sea-level. The Ishasha mine itself is situated at a height of 4500 feet in rugged country where slopes up to 40° are common (Fig. 31).

Drainage in this mountainous area is dominantly towards the north-west via the Ishasha River which flows into Lake Edward. The rivers and their tributaries are eroding vigorously, the swiftly flowing tributaries being fed by numerous small streams which often rise in water-logged areas at the heads of narrow, steep-sided gulleys.

Geology: The most widespread rocks in the Kigezi District are metamorphased sediments of the Karagwe-Ankolean System of Pre-Cambrian age (Combe, 1952). The Ishasha area is poorly

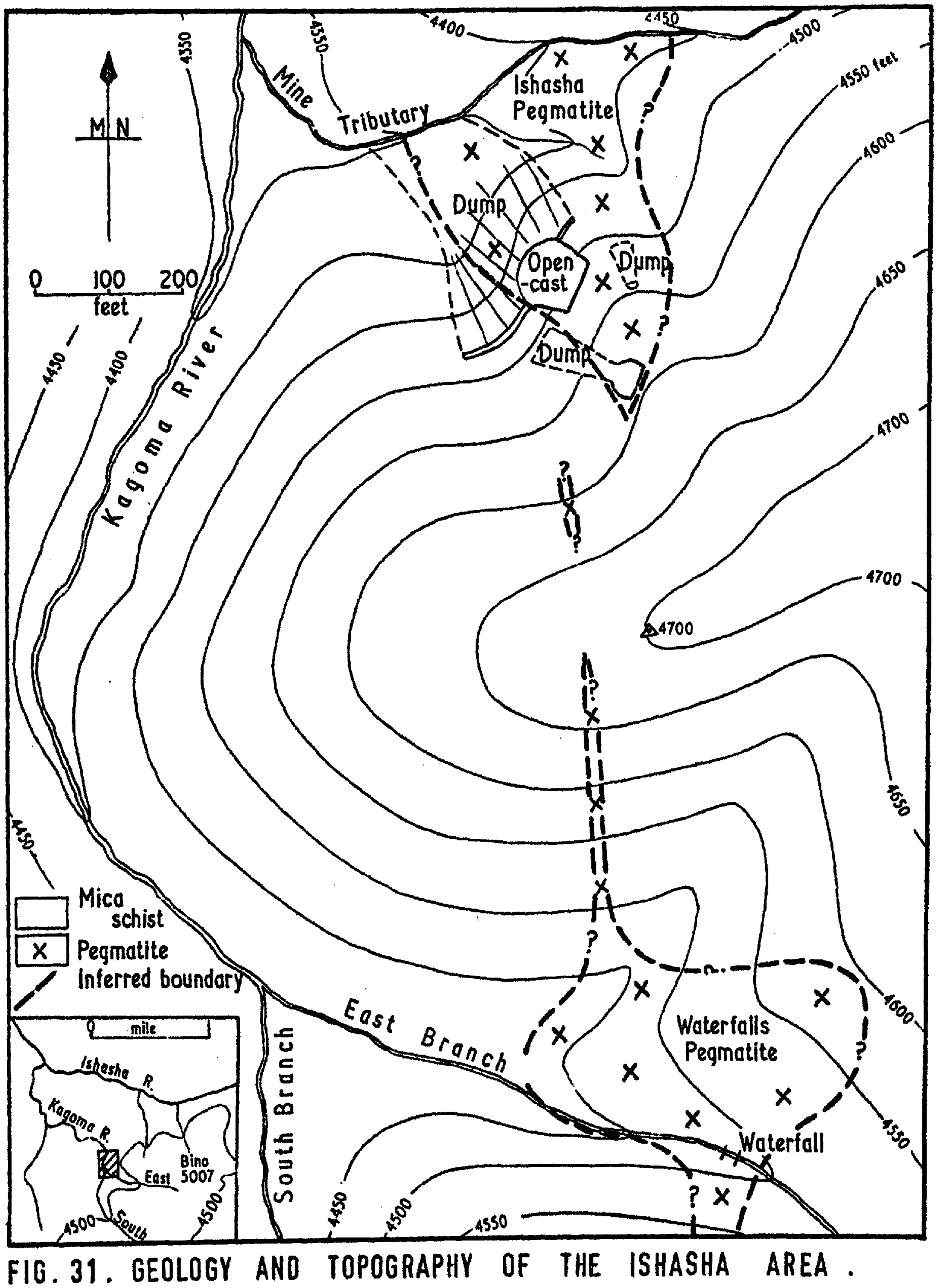


FIG. 31. GEOLOGY AND TOPOGRAPHY OF THE ISHASHA AREA.

exposed and little is known of the local geology. It is possible that the strong regional strike of 145°-160° persists and that intense isoclinal folding is responsible for the observed steep dips in bedding and cleavage. Granite occurs less than 2 miles south of the mine. Many pegmatites occur in the mica schists and at the contacts the schist usually has been extensively tourmalinised. It is possible that the pegmatites become enlarged at the intersections of strong shears with lines of weakness along fold axes.

The main pegmatites belong to the group of replaced muscovite-albite pegmatites in the Beus classification (Beus, 1956a).

The Ishasha pegmatite (Fig. 31) which is being mined for beryl has been described by Hawkes and Gallagher (1960). The body is possibly crescent shaped in plan, perhaps thickening at depth. The sequence of internal zoning appears to be as follows:-

Zone	Description	Width
Contact zone	Coarse perthitic felspar with subsidiary quartz and minor muscovite.	10-20 feet
Intermediate zone	Fine to medium-grained muscovite-quartz-albite-oligoclase pegmatite containing beryl and a little tantalite-columbite.	5-15 feet
Core	Massive quartz.	10-15 feet

In general the pale-green beryl crystals average $\frac{1}{2}$ to 2 in. across, although fairly large crystals are reported from the northern intermediate zone near the centre of the pegmatite.

During the course of the present study a new pegmatite body, referred to as the Waterfalls pegmatite (Fig. 31) was discovered as a result of stream sediment sampling in the Ishasha drainage system. The nature of this occurrence is not known but it is possibly similar to the Ishasha pegmatite described above.

The natural dispersion of Be from the Ishasha body could not be studied due to extensive contamination from the mine workings, and the detailed investigations were therefore carried out in the vicinity of the undisturbed Waterfalls pegmatite.

Overburden: Even on the steep hill-slopes, the soil cover is almost continuous and may be as deep as 6-8 feet at the bottom of slopes and in gulleys. The overburden is dominantly loamy with some evidence of profile differentiation. Below the mat of decaying organic material at the surface, there is a black organic-rich horizon to a depth of 9-24 in. ranging up to 60 in. or more in gulley colluvium. The underlying brown subsoil shows a gradual transition into weathered bedrock. Generalised profiles of soil developed over pegmatite and mica schist are described below.

Profile over pegmatite at 2650B

Depth (in.)	Horizon	Description	pH
0-3	Upper top-soil	Black loam with much roots, leaves and twigs; some pegnatite fragments up to 1 in. in size.	5.4
3-12	Topsoil	Black loamy-clay with roots; some quartz, mica and felspar gravel fragments up to 1 in. in size.	5.0
12-18	(transition)	Black-brown loamy-clay at top grading into grey-brown loamy-clay at bottom, with a little pegmatitic gravel material.	
18-29	Subsoil	Brown loamy-clay, grading from greyish-brown at top, with some pegmatite fragments up to 1 in. in size.	5.3
29-41	Lower subsoil	Some brown loamy-clay between fragments of weathered pegmatite material up to 4 in. diameter.	
41+	Bedrock	Weathered pegmatite, mostly felspar with some quartz and mica.	

Profile over schist, 2925B

Depth (in.)	Horizon	Description	pH
0-3	Upper topsoil	Brownish-black loam with much decomposing roots, leaves and twigs.	5.5
3-12	Topsoil	Loose black-brown loamy-clay with roots and much fine mica.	5.2
12-40	Subsoil	Very soft silver-brown loamy-clay with unconsolidated mica schist; some angular quartz fragments below 28 in.	5.0
40+	Bedrock	Soft weathered micaceous schist.	

The mineral composition of the coarse material in the topsoil horizon depends upon the bedrock further up the slope, from which much of the material has been derived. In the subsoil, the composition depends more upon the nature of the immediately underlying bedrock.

B. Distribution of Be at the Waterfalls Pegmatite

1. Pegmatite minerals

Samples of the principal pegmatite minerals from the Waterfalls dyke were analysed colorimetrically for Be. The values obtained for felspar and mica are similar to the instrumental data obtained by Hawkes and Gallagher (1960) on the corresponding minerals from the Ishasha pegmatite (Table 29).

TABLE 29

Be content of minerals from Waterfalls and Ishasha pegmatites, Ishasha

Mineral	p.p.m. Be	
	Colorimetric (Waterfalls)	Gamma-neutron assay (Ishasha)
Quartz	0.25	
Felspar	7.5	
Felspar (albite-oligoclase)		7
Muscovite	19	18

2. Soils

(i) Background and threshold values

True background values for soils derived from barren micaceous schist are difficult to obtain owing to the wide distribution of pegmatite veins throughout the area. The contents of 3-5 p.p.m. Be in the -190 micron fractions of samples from Profile S5 (Fig. 33) are the lowest recorded in profile samples. However, by virtue of the distribution of Be in the different size-fractions of these samples (Fig. 32), it is possible that even this profile is affected by pegmatitic material, or there may be locally disseminated Be minerals in the schist. Lower values of 1-2 p.p.m. Be are present in several samples of -190 micron material from the contour traverses (Fig. 37)

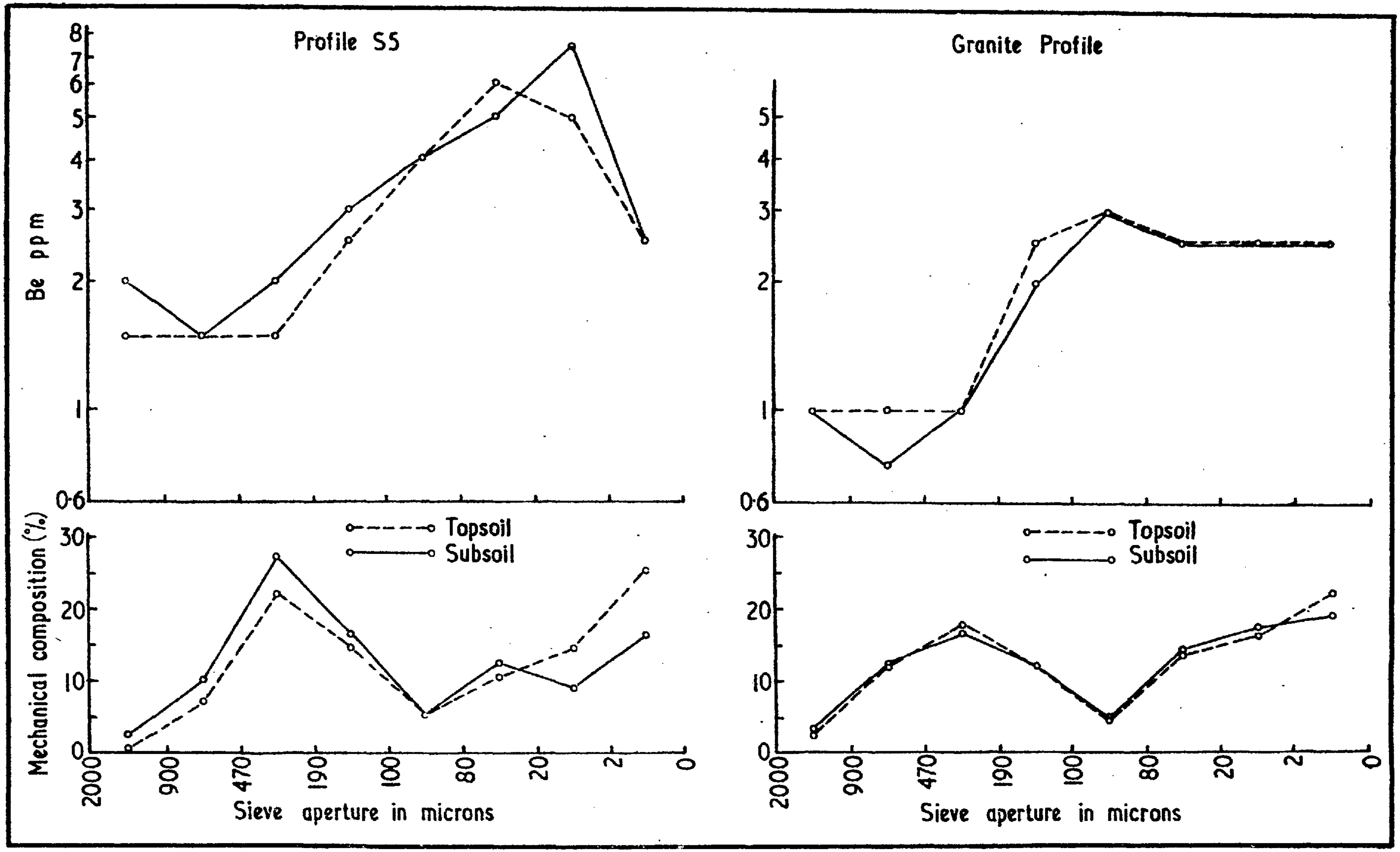


FIG. 32. MECHANICAL COMPOSITION AND Be DISTIBUTION IN SIZE-FRACTIONS OF BACKGROUND SOILS, ISHASHA. [Samples treated by sedimentation]

and it is more probable that these values represent the true local background for schist.

Granite soils, on the other hand, contain approximately 1 p.p.m. Be in the coarse fractions and 2.5-3 p.p.m. in the fine fractions (Fig. 32). Here, the clay fraction does not appear to carry the highest values, as is the case in soils developed over granite in the Bepe area (Table 7) and over gneiss in the Mistress area (Fig. 26).

In view of the relatively high local background values, the threshold has been taken, provisionally, as 7 p.p.m. Be.

(ii) Distribution of Be in the soil profile

There are no significant variations in the Be contents of the -190 micron fraction material within profiles over and in the vicinity of the Waterfalls pegmatite (Fig. 33), although in some cases there is a tendency for the metal to increase in tenor with depth, as in profiles S4, P2, P3 and G1. The Be values of topsoil samples are never significantly higher than those of the subsoil.

Data from the analysis of size-fractions of profile samples (Figs. 34 and 35) indicate an apparent bimodal distribution pattern of Be in the size-fractions of all anomalous samples, whether from soils over pegmatite, schist or gulley colluvium. One peak occurs in either of the two coarsest fractions and the other occurs in either the fine-sand (20-80 microns) or the silt (2-20 microns) fraction. The values given for the 900-2000 micron

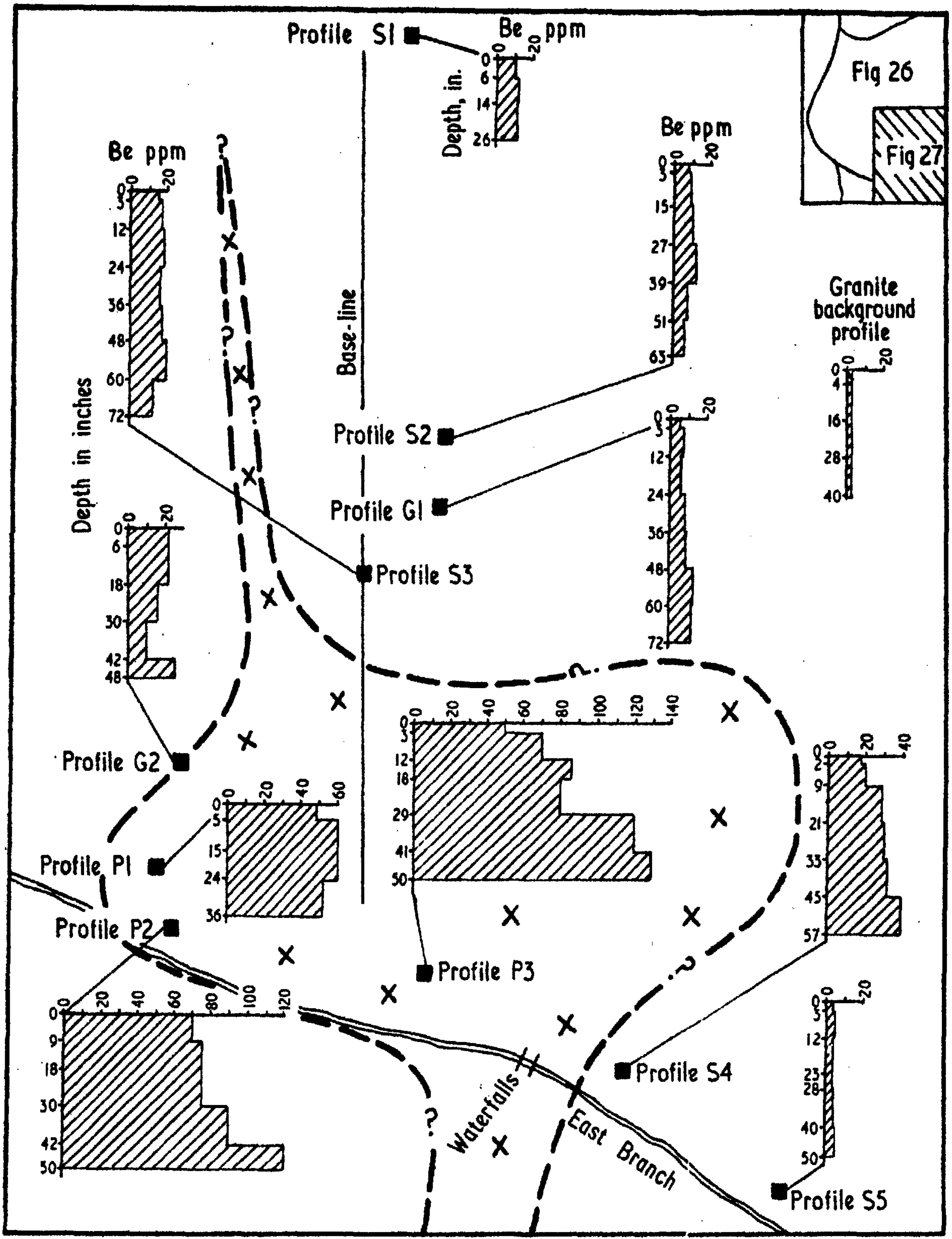


FIG. 33. DISTRIBUTION OF Be IN SOIL PROFILES (-190 micron fraction), ISHASHA.
[Samples dry-sieved]

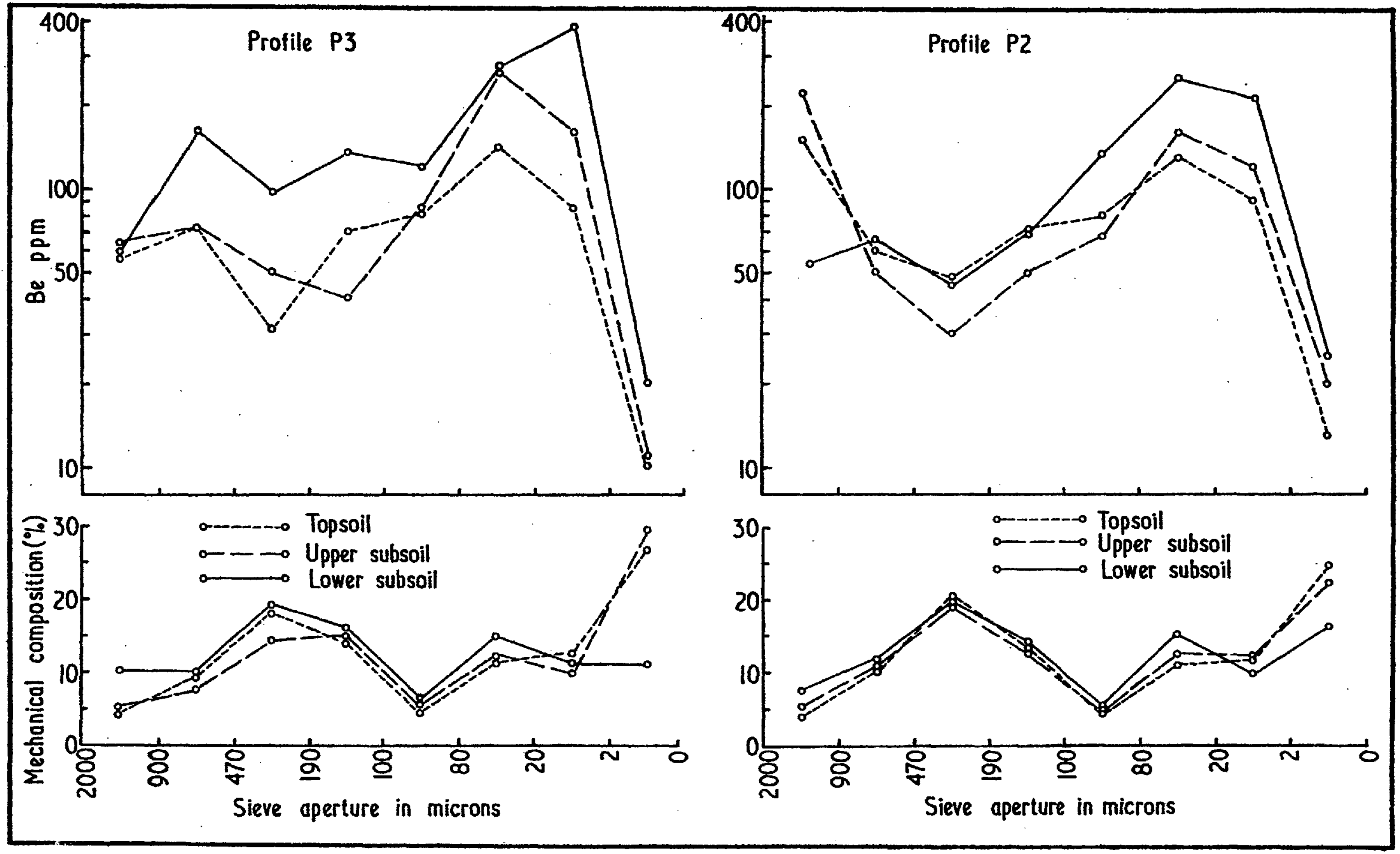


FIG. 34. MECHANICAL COMPOSITION AND Be DISTRIBUTION IN SIZE-FRACTIONS OF SOILS OVER PEGMATITE, ISHAHA (for location see Fig. 33).
[Samples treated by sedimentation]

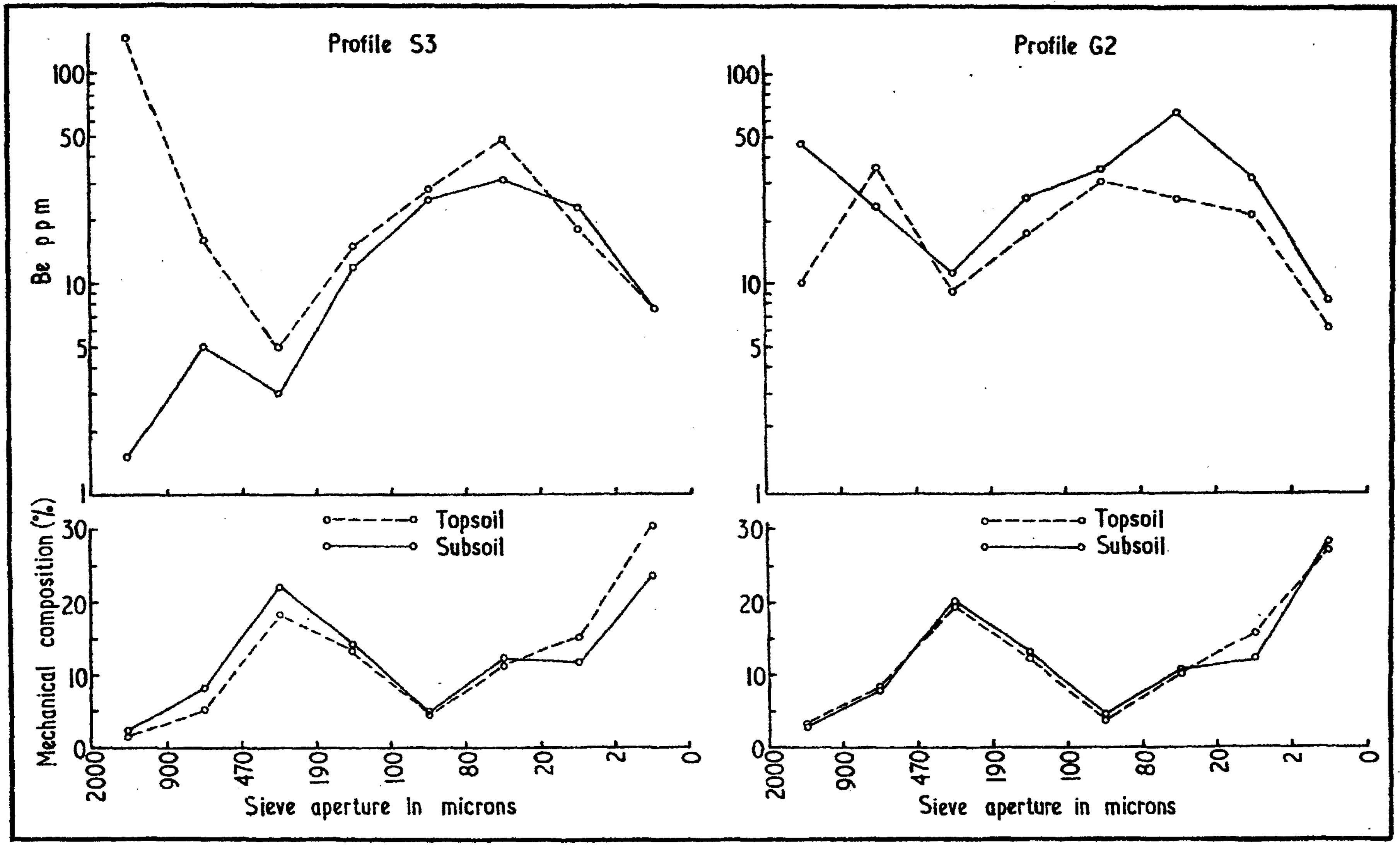


FIG. 35. MECHANICAL COMPOSITION AND Be DISTRIBUTION IN SIZE-FRACTIONS OF ANOMALOUS COLLUVIAL SOILS, ISHASHA (for location see Fig. 33)
[Samples treated by sedimentation]

fraction may not be truly representative, however, because for some samples only 1g of this material was available for analysis.

The clay fraction of anomalous soils invariably contains only relatively small amounts of Be as compared with the silt fraction. It is interesting to note that these low values may be eliminated, and relatively uniform values obtained, by analysing the oversize material, irrespective of which fraction is taken (Fig. 36). However, if undersize fractions are analysed there is a marked drop in Be values as the proportion of clay increases in the material treated.

Over pegmatite (profiles P2 and P3) the Be content of most size fractions is slightly higher in the subsoil than in the topsoil. In profile S3 (over schist), the high Be content of the coarse fractions of the topsoil are in direct contrast to the low values in similar material of the subsoil. Here, the Be content of the topsoil is affected by anomalous soil derived from pegmatitic material upslope.

(iii) Lateral distribution

As previously indicated, analysis of coarse fractions gives the wider anomaly in the Bepe area. At Ishasha, on the other hand, as a result of the high Be content of the fine soil fraction, there is little, if any, difference between the -190 and the 190-2000 micron fraction values from the prospecting point of view (Table 30).

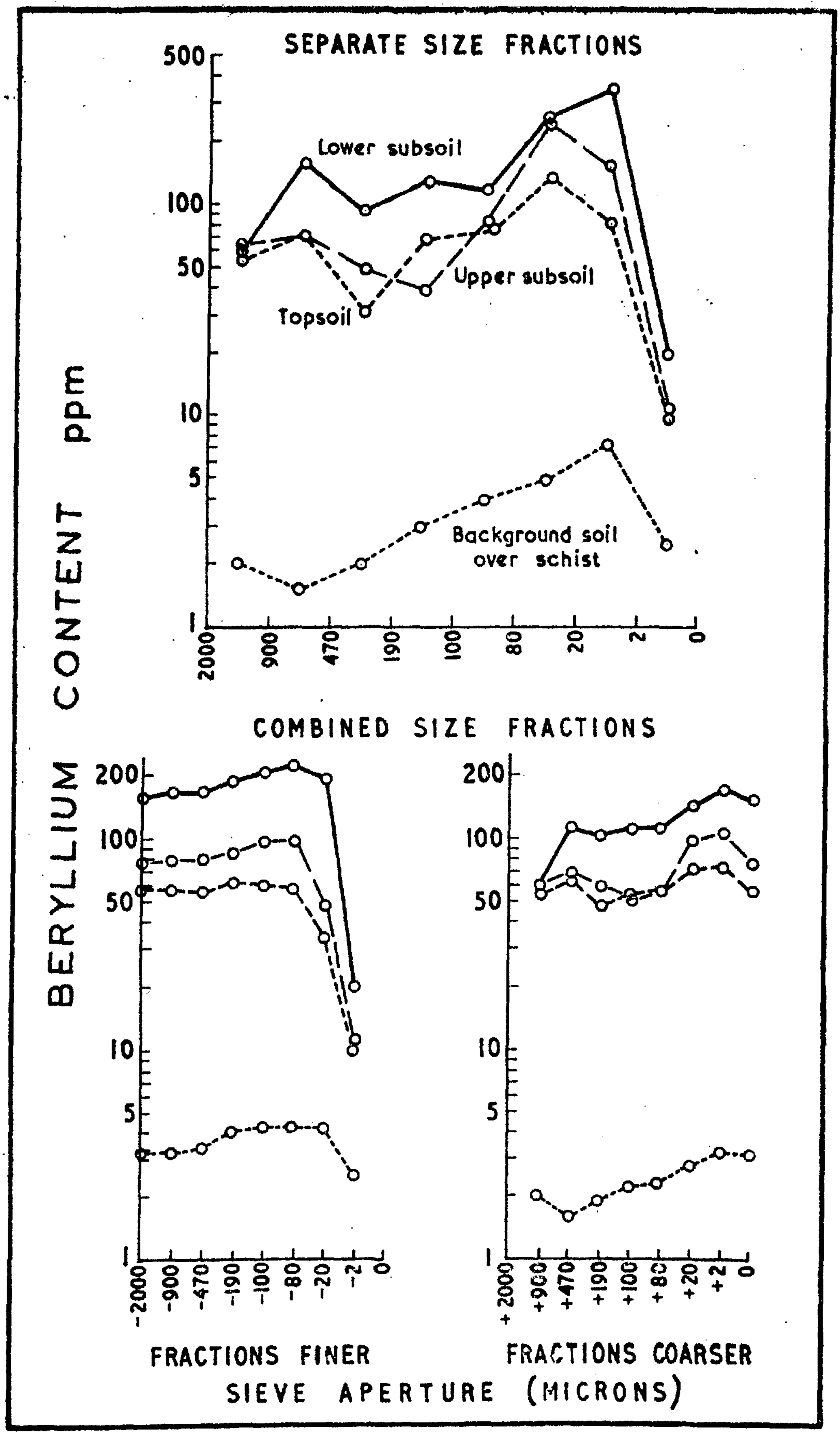


FIG. 36. EFFECT OF ANALYSING COMBINED SIZE-FRACTIONS OF SAMPLES FROM PROFILE P3, ISHASHA.

Furthermore, use of the -190 micron fraction avoids the necessity of crushing the sieved sample.

TABLE 30

Comparison of Be values for -190 and 190-2000 micron fractions of topsoils, Ishasha

Sample	p.p.m. Be	
	-190 microns	190-2000 microns
Topsoil, profile S3	18	16
" " G2	17	16
" " P3	62	47
Samples treated by sedimentation		

The results of contour soil sampling, based on analysis of the -190 micron fraction of topsoil samples (Fig. 37) indicate the presence of two significant anomalies, one over the Ishasha pegmatite and the other covering the Waterfalls occurrence. Anomalous values as high as 90 p.p.m. Be were obtained in uncontaminated soils near the Ishasha dyke, and Be contents up to 65 p.p.m. were present above the Waterfalls pegmatite.
It is possible that minor anomalous values, located upslope from each of the main pegmatite bodies, reflect extensions of the known occurrences.

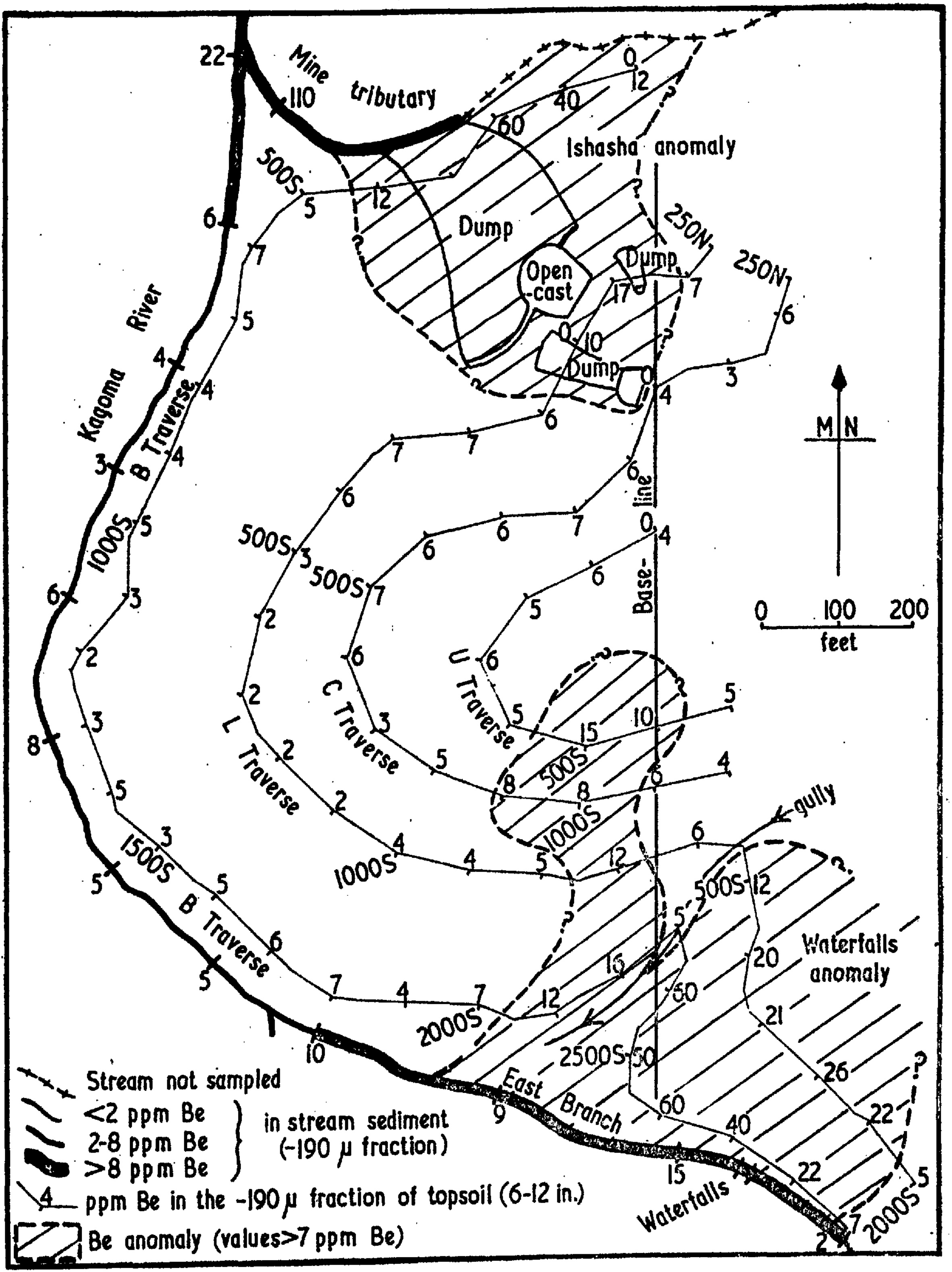


FIG. 37. DISTRIBUTION OF Be IN TOPSOIL AND STREAM SEDIMENTS (-190 micron fraction), ISHASHA.
[Samples dry-sieved]

(iv) Representivity

A point 35 feet upslope from sampling position 2700S on Traverse B (Fig. 37) at the Waterfalls pegmatite was selected for testing the representivity of topsoil samples in the same manner as at Bepe (p.74). The local topographic gradient was 1 in 1.7. The results (Table 31) indicate that apart from the upslope direction, a single sample is reasonably representative of the soil for a radius of at least 25-50 feet. Homogenization of the soil by creep on the steep slope is undoubtedly a factor.

TABLE 31

Lateral representivity of topsoil at the Waterfalls pegmatite, Ishasha

Distance from centre point (ft)	p.p.m. Be			
	north-east (upslope)	south-east (along slope)	south-west (downslope)	north-west (along slope)
3	50	50	56	50
6	30	50	44	58
12	46	56	66	46
25	28	54	68	50
50	28	46	68	29
	Value at centre point = 50 p.p.m. Be			
Data refers to dry-sieved -190 micron fraction,				

It is unlikely that similar results would invariably be obtained elsewhere in the area, particularly where the Be is erratically distributed in the bedrock.

(v) Comparison with spectrographic results

The different size-fractions of samples from profiles S5 and P3 were also analysed spectrographically (Table 32). Both sets of values discriminate between background and anomalous samples and show the same trends within any one sample. However, the spectrographic values show a consistent tendency to be higher than those obtained by chemical analysis. In this case, the spectrographic determinations were based on a D.C. anode arc technique using a simple C:sample mixture. Much better correspondence was obtained on the Bepe samples using $LiCO_3$ buffer (Fig. 21).

TABLE 32

Comparison of spectrographic and chemical Be values for soil samples, Ishasha

(Spectrographic analyses by Miss D. A. Poynter)

Fraction (microns)	Profile S5 on schist				Profile P3 on pegmatite					
	Topsoil		Subsoil		Topsoil		Upper subsoil		Lower subsoil	
	Spec.	Chem.	Spec.	Chem.	Spec.	Chem.	Spec.	Chem.	Spec.	Chem.
	p.p.m. Be				p.p.m. Be					
900-2000	-	1.5	n.d.	2	145	56	230	64	220	60
470-900	10	1.5	n.d.	1.5	200	72	220	72	290	160
190-470	n.d.	1.5	10	2	85	32	120	50	130	96
100-190	10	2.5	10	3	120	70	130	40	125	135
80-100	10	4	n.d.	4	250	80	80	85	130	120
20-80	15	6	10	5	320	140	210	260	250	270
2-20	10	5	10	7.5	180	84	160	160	600	370
0-2	10	2.5	n.d.	2.5	30	10	12	11	27	20

n.d. = not detected

Spectrographic sensitivity 10 p.p.m. Be using arc lines at 3130 and 3131 A^{o}.

(vi) Results for other elements

Determinations of a number of minor elements (Table 33) were made spectrographically by Miss D. A. Poynter on the samples given in Table 32.

TABLE 33

Minor elements in soil samples, Ishasha

Profile	Horizon	Fraction microns	Element, p.p.m.												
			Mn	Pb	Sn	Ga	V	Ti	Ni	Zr	Cr	Li	Rb	Ba	Sr
S5 (schist)	Topsoil 0-12 in.	470-900	200	45	nd	8	40	1800	nd	150	80	22	nd	250	20
		190-470	200	20	nd	10	55	2500	30	220	130	60	nd	300	28
		100-190	280	30	nd	25	80	5000	30	140	120	130	250	350	70
		80-100	350	30	nd	20	80	5000	40	130	150	130	500	350	80
		20-80	350	40	nd	20	80	5500	160	1800	160	90	150	300	40
		2-20	500	160	nd	35	120	4000	400	320	900	90	150	320	80
		0-2	3500	150	25	35	400	7500	160	350	250	130	500	350	110
S5 (schist)	Subsoil 12-50 in.	900-2000	90	40	nd	40	160	4200	30	600	130	300	700	600	80
		470-900	130	20	nd	20	130	3200	50	420	160	300	900	450	70
		190-470	160	20	nd	28	140	3500	60	270	180	320	900	450	90
		100-190	500	20	nd	22	150	6000	60	200	250	320	800	400	80
		80-100	350	35	nd	22	80	4000	60	200	140	280	700	450	80
		20-80	270	35	22	15	80	4200	110	1100	160	250	400	320	70
		2-20	130	60	22	15	70	2000	270	350	210	250	350	320	60
		0-2	230	200	18	18	220	4300	120	400	130	100	120	60	8

TABLE 33 (Cont'd.)

Minor elements in soil samples, Ishasha

Profile	Horizon	Fraction microns	Element, p.p.m.												
			Mn	Pb	Sn	Ga	V	Ti	Ni	Zr	Cr	Li	Rb	Ba	Sr
P3 (pegmatite)	Topsoil 0-12 in.	900-2000	200	30	nd	3	25	700	nd	nd	12	20	100	320	25
		470-900	270	28	nd	3	15	700	nd	110	10	20	nd	40	20
		190-470	260	20	nd	4	15	1400	nd	160	10	25	nd	60	30
		100-190	650	40	nd	5	18	1800	nd	110	25	30	nd	60	28
		80-100	320	30	20	10	35	2000	55	130	100	50	120	110	50
		20-80	600	55	25	10	50	5500	200	1800	350	90	400	200	80
		2-20	1800	180	50	20	120	5500	560	400	1000	160	1200	400	110
		0-2	800	90	40	20	120	4000	90	140	140	160	600	320	80
P3 (pegmatite)	Upper Subsoil 12-41 in.	900-2000	120	75	nd	3	15	900	nd	nd	10	60	350	130	40
		470-900	120	35	nd	3	15	900	nd	100	10	40	200	90	20
		190-470	200	25	nd	4	15	1500	nd	160	10	40	100	80	22
		100-190	250	20	nd	5	15	1800	100	100	110	22	100	60	22
		80-100	300	27	nd	7	15	2000	nd	nd	25	40	100	90	25
		20-80	600	68	35	6	28	5000	320	700	160	100	120	120	50
		2-20	580	90	25	7	32	2500	180	180	150	150	500	300	80
		0-2	1800	150	45	16	140	4000	100	160	100	100	200	160	15
P3 (pegmatite)	Lower Subsoil 41+ in.	900-2000	6	250	nd	6	nd	nd	nd	nd	nd	20	1000	80	28
		470-900	5	220	nd	6	nd	nd	nd	nd	nd	20	1100	40	22
		190-470	4	80	nd	7	nd	nd	nd	nd	nd	12	300	12	5
		100-190	4	60	nd	7	nd	nd	30	nd	40	6	150	14	6
		80-100	5	60	nd	7	nd	150	130	nd	140	8	200	27	15
		20-80	20	75	nd	7	nd	240	300	nd	700	13	350	22	7
		2-20	75	110	37	6	60	1200	500	nd	1300	120	350	120	50
		0-2	240	270	67	11	120	4000	100	160	300	100	150	50	4
Limits of detection			3	8	18	2	15	100	30	100	10	1	100	8	3

n.d. not detected

The results are summarized below:

(a) Positive anomaly over the pegmatite: Sn (2-fold anomaly in fine fractions only).

(b) "Negative anomaly" over the pegmatite: Ga, Ba, Zr?, V?,
Cr (coarse fractions only),
Ti "
Li "

(c) No distinct trends: Mn, Pb, Ni, Rb, Sr.

It is apparent that no other element produces contrasts comparable to those given by Be.

The data for Rb values (Table 33), particularly those for profile P3, are interesting in that they illustrate the transfer of this metal from the coarse to the fine fractions on passing up a profile, i.e. as the weathering processes advance. In the deeper samples Rb is almost certainly present mainly as a minor constituent in relatively fresh or partially weathered felspar. On weathering, the Rb is liberated but part at least tends to remain in the soil associated with the clay mineral weathering-products of the rock-forming minerals.

It is probable that any Be similarly released by weathering of felspar and mica would behave in the same way. This is not the case, however, with Be combined in the mineral beryl, as demonstrated by a detailed investigation into the form of the Be in the 20-80 micron fraction of the lower subsoil sample from profile P3 which contains 270 p.p.m. Be (Table 32). Successive separations of this material, using heavy liquids, resulted in a concentrate containing 30 per cent beryl (identified by J. M. Gallagher).

(vii) <u>Base-exchange capacity of clay and exchangeable-Be</u>

The base-exchange capacity of several clay samples (Table 34) were determined by the method described in Appendix I. The exchangeable-Be content was then determined on the leachate from the base-exchange capacity procedure.

There is no apparent relationship between the amounts of exchangeable-Be and the base-exchange capacity of the clays. The exchangeable-Be values, however, were obtained from determinations made at the extreme lower limit of the working range of the analytical method and the precision is probably very poor.

TABLE 34

Base-exchange capacity and the content of exchangeable and readily-soluble Be in the clay fraction of soil, Ishasha

Parameter	Profile					
	P3 on pegmatite			G2 in gulley colluvium		S5 on schist
Depth (in.)	0-12	12-41	41+	0-42	42-48	12-50+
Material	Top-soil	Sub-soil	Weathered bedrock	Top-soil	Sub-soil	Sub-soil
Weight % of total	26.6	29.7	11.1	27.2	28.5	16.5
pH	5.4	5.0	5.3	6.0	6.4	5.0
Base-exchange capacity (milli-equivalents/100g)	6.7	6.5	9.6	9.8	8.7	10.0
Exchangeable-Be (p.p.m.)	0.2	0.1	0.3	0.3	0.25	n.d.
" (% of total)	2.0	1.0	1.5	5.0	3.0	-
Readily-soluble Be (p.p.m.)	3.0	2.5	2.5	1.5	2.0	0.5
Readily-soluble Be (% of total)	30	23	12.5	25	25	20
Total Be (p.p.m.)	10	11	20	6	8	2.5

(viii) Readily-soluble Be

In addition to the exchangeable-Be determinations considered above, the original clay samples were treated with cold 0.2N nitric acid and the readily-soluble Be determined by analysing this extract (Table 34). The values are much higher than those for exchangeable-Be and there may be some significance in the decrease in readily-soluble Be from 30 to 12.5 per cent with increasing depth in the profile P3 on pegmatite.

3. Stream sediments

Stream sediment samples were collected at a number of points in the Kagoma River and its tributaries, including those which drain the two main pegmatites. The streams were flowing rapidly during the period of sample collection.

(i) Background and threshold values

The background values obtained in the reconnaissance sediment sampling survey (Fig.40) fall within the range <1-2 Be for the -190 micron fraction, giving a threshold value of 2 p.p.m.

The mechanical composition and the distribution of Be within the size fractions is roughly similar for all the background samples studied (Fig. 38, sample nos. 1 and 2, and regional background). There is a tendency to a bimodal Be distribution, although the highest values occur predominantly in the fine fractions. The local background samples may possibly be influenced by minor amounts of pegmatitic material derived from within the catchment areas, or by feeble dissemination of Be minerals in the schist.

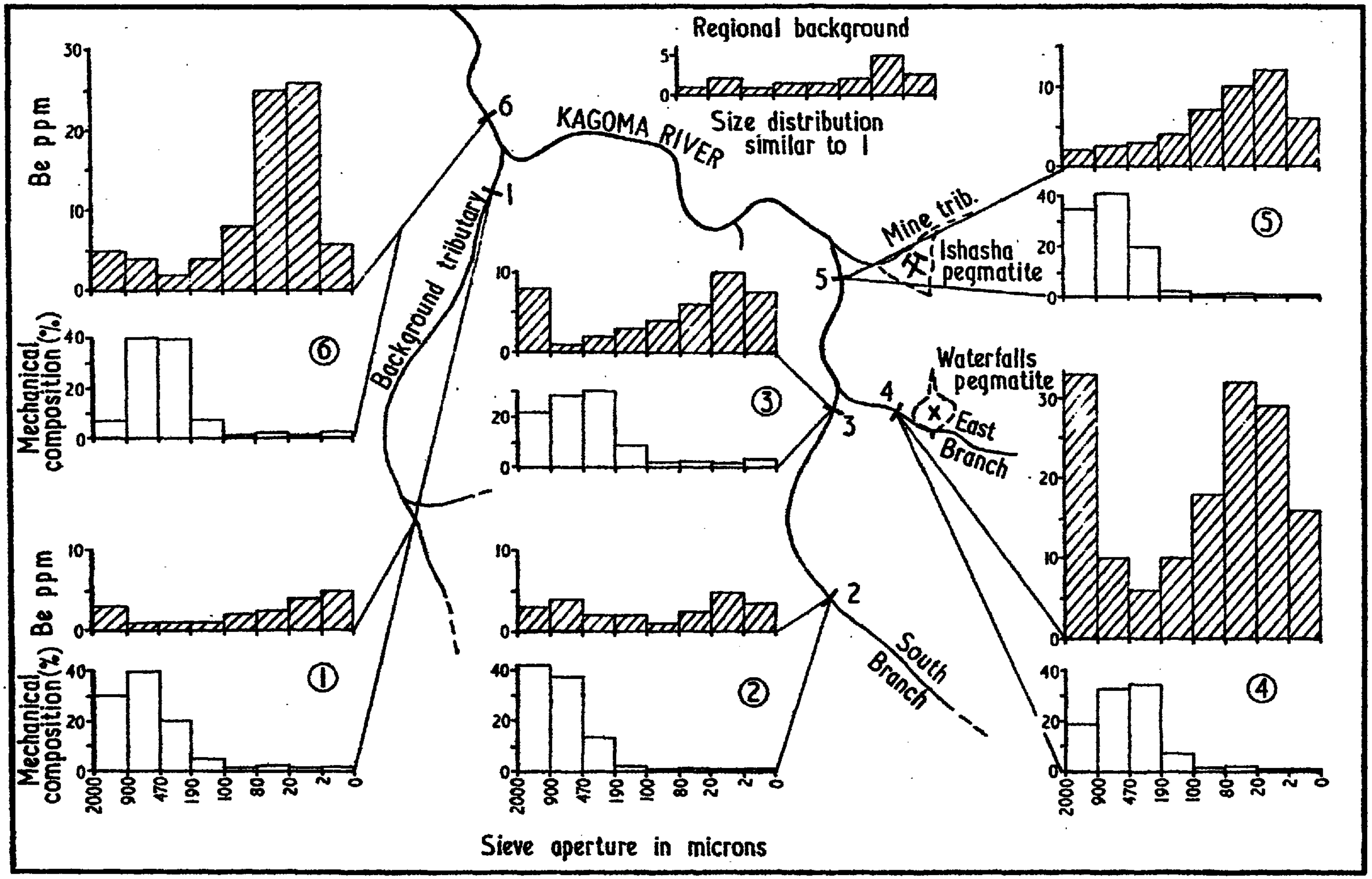


FIG. 38. MECHANICAL COMPOSITION AND Be DISTRIBUTION IN SIZE-FRACTIONS OF STREAM SEDIMENT, ISHASHA (Samples collected by J. Lister). [Samples treated by sedimentation]

The values given by sample no. 1 are considered to be representative of the local background. The 190-2000 micron fraction contains 1.0 p.p.m. Be and the -190 micron fraction value is 2.3 p.p.m. (Fig. 39). The threshold values are taken as 3.0 p.p.m. Be for each fraction.

(ii) <u>Reconnaissance samples</u>

Reconnaissance stream sediment samples (-190 micron fraction) were collected at 250 feet intervals along the drainage (Fig. 40). Strong anomalous Be values occur downstream from the Ishasha mine, and additional anomalous Be contents in sediments from the East Branch of the Kagoma River led to the discovery of the Waterfalls pegmatite.

Near the Waterfalls dyke, the 190-2000 micron fraction gives an anomaly contrast of 13 compared with 7 for the -190 micron fraction (Fig. 39). Downstream, however, the contrast is slightly in favour of the fine fraction, which gives a contrast of 2.9 as compared to 2.4 for the coarse fraction. For this reason, and the fact that it is not necessary to crush the fine fraction prior to analysis, the -190 micron fraction was used for routine sediment sampling in this area. In actual fact, detailed examinations subsequently carried out in the laboratory show that rather greater contrast would have been achieved by analysing the -100 micron material, since this would have eliminated the low-grade 100-190 micron fraction which usually comprises about 50 per cent of the -190 micron material (see Fig. 38).

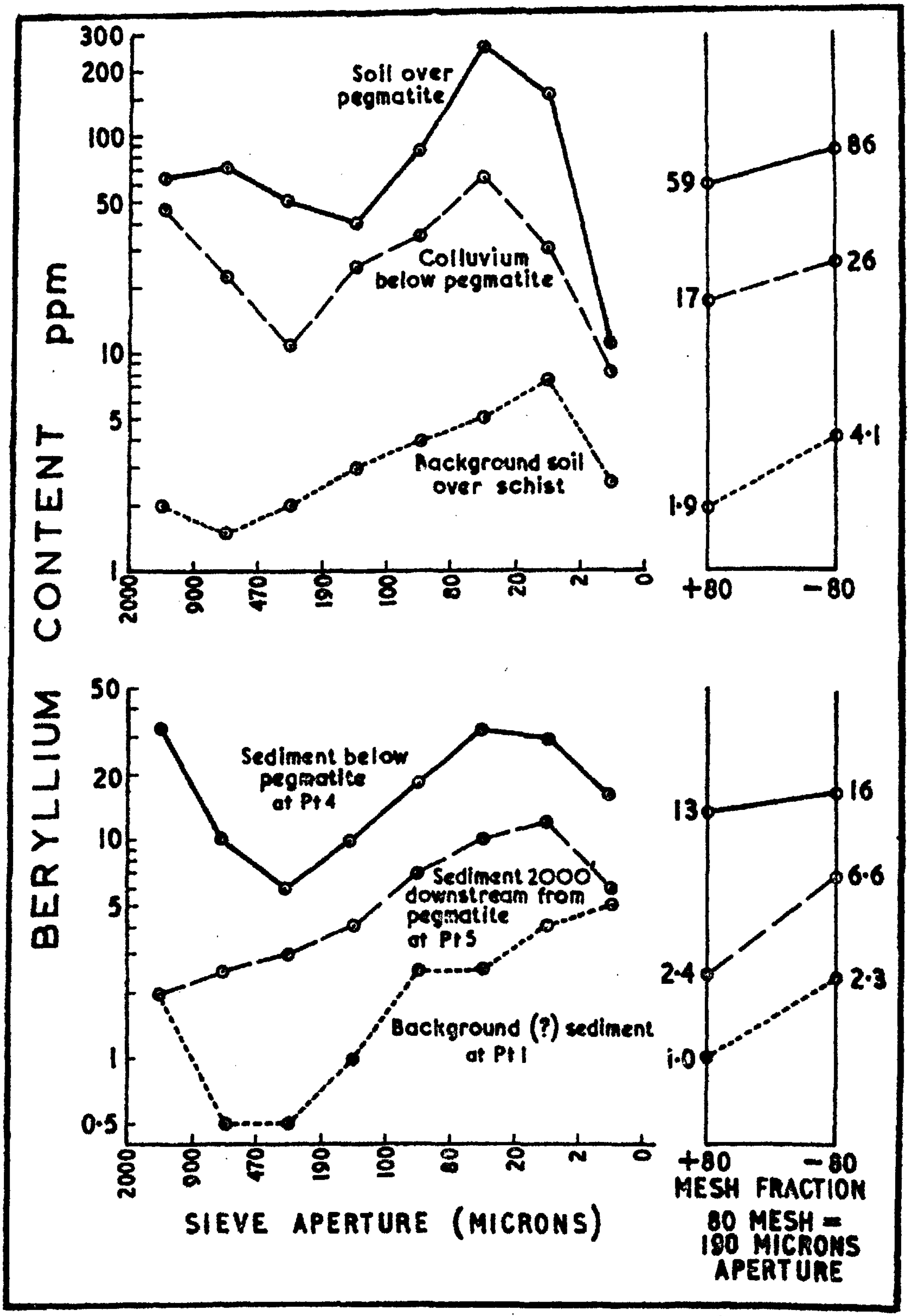


FIG. 39. Be DISTRIBUTION IN SIZE-FRACTIONS OF SOIL, COLLUVIUM AND STREAM SEDIMENT SAMPLES, ISHASHA. [Samples treated by sedimentation]

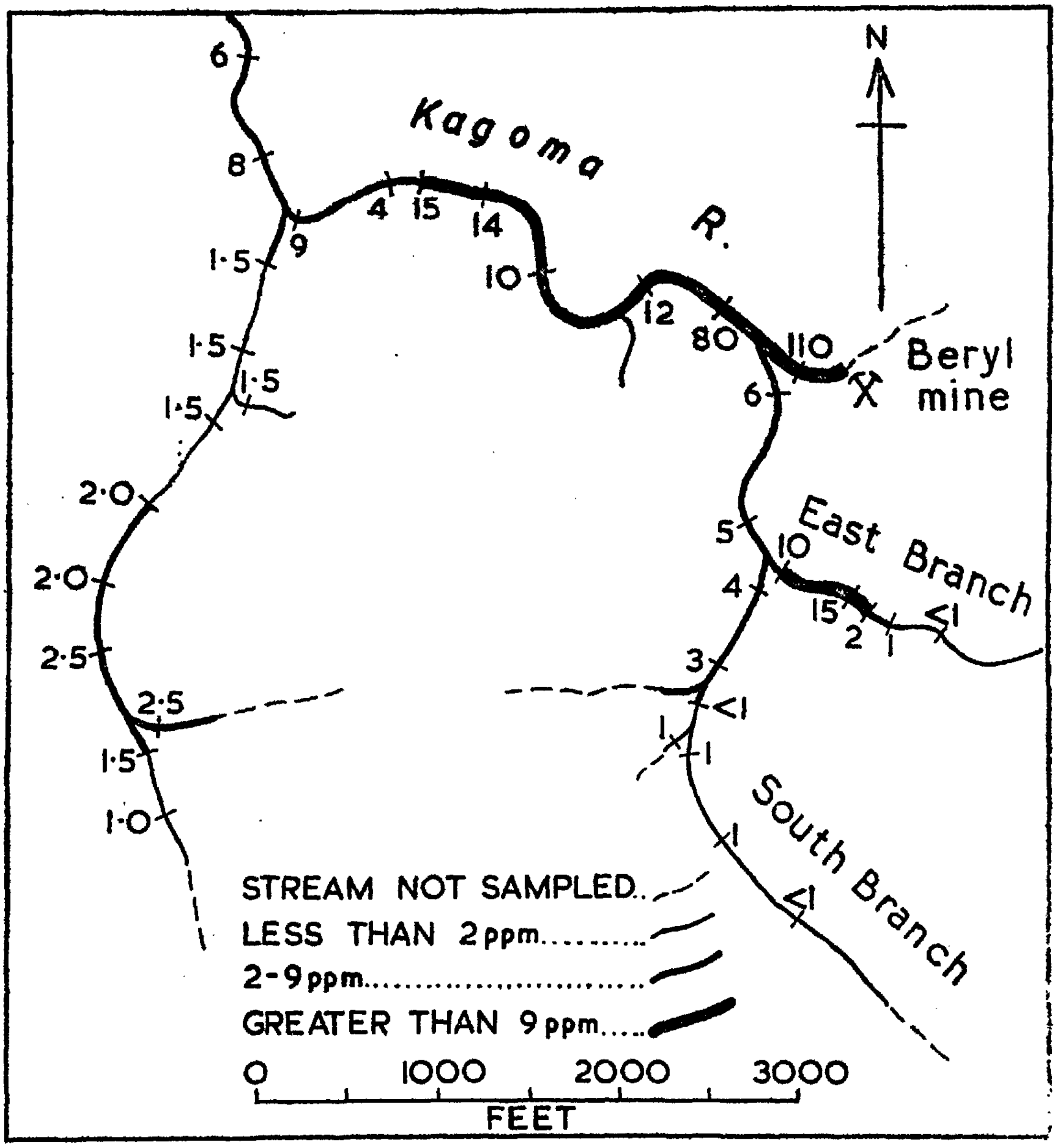


FIG. 40. DISTRIBUTION OF Be IN STREAM SEDIMENTS (-190 micron fraction), ISHASHA.
[Samples dry-sieved]

(iii) Distribution of Be in size-fractions of anomalous stream sediment

Bulk sediment samples of 3 Kg each were collected from points in the Kagoma River and its tributaries (Fig. 38). The distribution of Be in the various fractions was determined after the samples were separated into size-fractions by the sedimentation procedure (Appendix I).

The mechanical composition data show that the greater part of the sediment samples consists of coarse material with particle-size greater than 100 microns.

Sample no. 3, shown to be slightly anomalous in the reconnaissance survey, displays a distinct bimodal pattern of Be distribution, with values in the coarse and fine fractions 2-3 times greater than background. It is considered probable that this sample is partly composed of material derived from pegmatite, possibly a southerly extension of the Waterfalls body.

Sample no. 4, collected downstream from the Waterfalls pegmatite, contains anomalous Be values in all fractions. Bimodal distribution of the Be is particularly pronounced. This pattern of distribution of values is strikingly similar to that which occurs in the soil and colluvium overlying pegmatite (Fig. 39).

At sample point no. 5, 2000 feet downstream from the Waterfalls pegmatite (but upstream from the confluence with the mine tributary), anomalous Be contents persist in the fine material, although the tenor is reduced. The absence of a peak in the coarse fractions is possibly due to poor representivity as only 10 g from a total 800 g of each of the 900-2000 and 470-900 micron fractions was crushed for chemical analysis. From Table 12 it may be shown that the sampling precisions thereby attained were >100 per cent and 40 per cent respectively. Analysis of an 80 g sample by the gamma-neutron instrument (by J. M. Gallagher) gave values of 8 p.p.m. and 10 p.p.m. for the 900-2000 and 470-900 micron fractions, respectively. In this case the sampling precisions are 50 and 15 per cent, so that these values are probably much nearer the true Be contents for these fractions.

The high Be value in the fine material of sample no. 6 reflects the addition of material from the mine workings. Nevertheless, mining is unlikely to influence greatly the size distribution of the Be mineral, and the fact that these fine-fraction values are high in Be is considered to support the assumption made previously that the nature of the Waterfalls pegmatite is possibly similar to that of the main Ishasha pegmatite. The absence of high Be contents in the 900-2000 and the 470-900 micron fractions of sample no. 6 may be due also to poor sampling precision.

(iv) Representivity

Representivity in the -190 micron fraction was tested by collecting samples at points between two of the original reconnaissance sample positions (Table 35). All the values were determined on separate samples (i.e. where two values are given, these refer to duplicate samples and not to duplicate values for the same sample). The data show that there is a reasonable measure of agreement between samples taken at any particular point.

TABLE 35

Representivity of the -190 micron fraction of stream sediment, Ishasha

Sample Point	Distance downstream from point 31 (ft)	p.p.m. Be	Original value, determined in the field (p.p.m. Be)
31	0	9	15
(at Waterfalls pegmatite)	3	14	
	6	12, 13	
	12	18, 9	
	25	6, 4	
	50	8, 8	
	100	6, 6	
	200	4, 8	
	250		9
Samples dry-sieved and uncrushed.			

Furthermore, all the values are distinctly anomalous. The difference between the Be content of the samples at 3-12 feet and the others is possibly due to variations in the proportion of the Be-poor 100-190 micron fraction, a factor which could have a marked effect on the overall value of the -190 micron material. As mentioned earlier, representivity would probably be improved by testing only the -100 micron fraction.

Reference has already been made to the poor representivity achieved with the 900-2000 and the 470-900 micron fractions.

(v) Comparison with spectrographic and gamma-neutron assay results

In Table 36 some spectrographic Be values (determined by Miss D. A. Poynter) for size-fractions of stream sediment samples are compared with the corresponding chemical values. The discrepancies produced by the two analytical methods are particularly marked in the coarse fractions and may be due in part to poor representivity, having regard to the small samples taken for analysis. There is, however, an overall trend for the chemical value to be much lower than that given by spectrography for the same sample.

TABLE 36

Comparison of spectrographic and chemical Be values for stream sediment samples, Ishasha

Fraction (microns)	p.p.m. Be					
	Sample No. 4		Sample No. 5		Sample No. 1	
	Spec.	Chem.	Spec.	Chem.	Spec.	Chem.
900-2000	280	33	10	2.0	25	2.0
470-900	100	10	10	2.5	less than 10	0.5
190-470	20	6	10	3	"	0.5
100-190	50	10	10	4	"	1.0
80-100	50	18	10	7	"	2.5
20-80	55	32	10	10	"	2.5
2-20	50	29	14	12	10	4
0-2	30	16	15	6	less than 10	5

Samples treated by sedimentation

Check samples were assayed by J. M. Gallagher with the laboratory gamma-neutron instrument (Table 37). In general the gamma-neutron assay values fall between those given by the other two methods. It is possible that inadequate chemical attack or extraction, due to the types of minerals contained in the sediment (see p.28), is responsible for the low chemical values.

TABLE 37

Comparison of Be values for various size-fractions of stream sediment sample No. 4, Ishasha, determined by different analytical methods

Fraction (microns)	p.p.m. Be		
	Spectrography	Gamma-neutron assay	Colorimetry
900-2000	280	150	33
470-900	100	54	10
190-470	20	25	6
100-190	50	29	10
80-100	50	32	18
Analytical precision	±50	±30	±20

Nevertheless, despite the marked analytical bias, anomalous values are readily recognised, no matter which method is used for analysis.

(vi) Results for other elements

Miss D. A. Poynter also determined spectrographically the contents of several minor elements in the stream sediment samples nos. 1, 4 and 5 (Table 38).

TABLE 38

Minor elements in stream sediment samples, Ishasha

Sample No. (see Fig 38)	Fraction (microns)	Element, p.p.m.												
		Mn	Pb	Sn	Ga	V	Ti	Ni	Zr	Cr	Li	Rb	Ba	Sr
4 (below Waterfalls pegmatite)	900-2000	180	20	20	6	25	1800	nd	130	100	25	120	200	16
	470-900	100	12	20	5	20	1800	nd	130	30	35	100	120	13
	190-470	180	18	100	5	25	1800	nd	320	50	40	100	150	20
	100-190	250	10	20	6	30	4500	35	150	100	80	150	220	50
	80-100	250	30	40	10	55	4000	60	200	120	100	300	280	70
	20-80	400	55	20	12	100	10000	100	1500	180	100	200	280	70
	2-20	1800	200	60	20	180	6000	1800	320	5000	100	350	350	90
	0-2	250	170	25	8	100	1800	70	110	40	50	150	280	15
5 (2000 feet downstream from pegmatite)	900-2000	180	20	nd	5	15	1400	nd	nd	10	35	250	450	80
	470-900	180	20	nd	4	15	1600	nd	280	10	20	300	450	80
	190-470	200	15	nd	6	25	2000	nd	160	12	30	250	350	70
	100-190	350	18	nd	10	50	5000	35	1000	100	130	500	350	80
	80-100	700	35	nd	14	150	>10000	100	1400	180	150	700	350	90
	20-80	600	55	nd	18	130	>10000	80	1000	160	150	900	400	100
	2-20	1400	150	70	14	120	5000	1800	320	2000	130	700	350	100
	0-2	1800	180	90	18	180	4000	180	160	180	120	120	320	90
1 (background)	900-2000	800	14	nd	12	80	2000	nd	160	100	110	200	300	70
	470-900	200	12	nd	6	30	1800	nd	160	30	90	250	320	80
	190-470	500	20	nd	18	50	>10000	30	2000	90	160	120	300	70
	100-190	500	25	nd	18	60	>10000	30	1800	140	160	120	350	90
	80-100	700	25	nd	18	100	>10000	30	750	180	200	500	500	110
	20-80	450	45	nd	18	120	8000	120	1800	200	200	1100	500	130
	2-20	700	150	35	16	180	2500	1800	800	2000	130	700	350	70
	0-2	500	220	45	18	160	2500	100	100	140	110	400	300	50
Limits of detection		3	8	18	2	15	100	30	100	10	1	100	8	3

The results are summarized below:

(a) Positive anomaly with respect to the pegmatite: Sn (in all fractions except clay);

(b) Negative anomaly with respect to the pegmatite: Li (3-fold anomaly in coarse fractions only);

(c) No distinct trends: Mn, Pb, Ga, V, Ti, Ni, Zr, Cr, Rb, Ba and Sr;

(d) There is a marked concentration of Ni and Cr in the silt fraction of all samples.

As was the case for soils the greatest contrast is again given by Be.

(vii) Base-exchange capacity of clay and exchangeable-Be

The base-exchange capacity and exchangeable-Be values of stream sediment clays (Table 39) were determined in the manner described for soil-clays (p.121). There does not appear to be any correlation betwen the base-exchange capacity of the clays and their percentage content of exchangeable-Be. As mentioned earlier, however, the analytical precision is poor at this level of exchangeable-Be content (see p.121).

TABLE 39

Base-exchange capacity and the Content of exchangeable and readily-Soluble Be in the clay fraction of stream sediment, Ishasha.

Sample No.	Weight % of total	pH	Base-exchange capacity (milli-equivalents per 100g)	Ex-changeable Be		Readily-soluble Be		Total Be (p.p.m.)
				p.p.m.	% of total	p.p.m.	% of total	
4 (at pegma-tite)	1.1	6.6	7.1	0.5	3	6	37	16
1 (back-ground)	1.0	6.6	4.8	0.2	4	2.5	50	5

(viii) Readily-soluble Be

The stream sediment clays were also treated with cold 0.2N nitric acid to determine the amount of readily-soluble Be present (Table 39). The points of interest are:

(a) The values are approximately 10 times higher than those of exchangeable-Be in the same sample;

(b) The contrast of the anomalous value is almost the same for the readily-soluble Be as for the total Be.

The above comparisons can only be considered as a rough guide due to the rather inadequate data, which embraces only one anomalous and one background sample.

4. Water

Four water samples were collected and tested (Table 40) by the method described in Appendix I.

TABLE 40

Be content of water samples, Ishasha

Sample No.	Location	pH	p.p.m. Be
1	Tributary draining the Ishasha mine.		0.02
2	Kagoma River, below confluence with mine tributary.		0.0005
3	East Branch of the Kagoma River, below Waterfalls pegmatite (at sediment sample point no. 4, Fig. 38)	6.6	0.001
4	Background tributary (at sediment sample point no. 1, Fig. 38)	6.6	0.0005

Although the results for samples 2, 3 and 4 lie near the limit of sensitivity for the analytical method, the slight increase above background of the amount of Be in the stream water downstream from the Waterfalls pegmatite may be significant. Thus it is not impossible that the groundwater draining the Waterfalls pegmatite may carry a similar concentration of Be to that draining the Ishasha pegmatite, and that the content has been diluted on entering the stream which is draining a catchment area of approximately $\frac{1}{3}$ square mile. Whether an undisturbed pegmatite would give a similar Be value to that obtained in the water of the mine tributary is not known.

It is unlikely, however, that the high content of 0.02 p.p.m. Be in the water of the mine tributary is due to suspended material. One gram of clay with a tenor of 20 p.p.m. Be would have to be present in 1 litre of water to produce such a content, and this quantity of suspended matter was not observed. Filtering removed coarser particles.

In comparison to the results at Ishasha given above, one sample of stream-water from Bepe, collected by J. S. Webb from the stream which intersects the Bepe 2 dyke at the Luck Bean open-cast, contained only 0.0005 p.p.m. Be.

Hem (1959) considers that because Be does not go into solution to any appreciable degree, it is not likely to be found in natural waters in greater than trace amounts. The element has been located in sea-water; Green (1959) gives a content of 1×10^{-7} p.p.m. Be in the ocean, and Merrill *et al.* (1960) report 5×10^{-7} p.p.m. Be. Other values of Be in waters include 0.001 p.p.m. in meteoric spring waters (Strock, 1941), up to 0.004 p.p.m. in hot spring waters (Kuroda, 1940), and up to 0.06 p.p.m. in some Transbaikalian carbonate springs (Beus, 1956b).

C. Summary

1. The main features which distinguish the Ishasha area from the Southern Rhodesian areas are the higher rainfall which is spread

more evenly throughout the year, the rugged topography, the deep soil cover and dense tropical forest vegetation.

2. The Ishasha pegmatites probably belong to the group of replaced muscovite-albite pegmatites in the Beus classification. In pegmatites of this type, much of the beryl is usually medium-grained ($\frac{1}{2}$-2 in. diameter).

3. Background Be contents of soils appear to vary between 1-5 p.p.m. or more (-190 micron fraction). The threshold value is provisionally taken as 7 p.p.m.

4. Anomalous amounts of Be, up to 90 p.p.m., occur in the overburden above pegmatites. If these are located on steep slopes the anomalous material is possibly transported many hundreds of feet to the valley bottoms where it can be detected by testing the topsoil of samples in base-of-slope traverses.

5. There are no significant trends in the distribution of Be within the soil profiles.

6. There is a distinct bimodal distribution of Be values in the size-fractions of anomalous soils and colluvium. Thus, high Be contents occur in the two coarsest fractions (470-2000 microns), and in the 2-80 micron fractions. This bimodal pattern of Be distribution may be a characteristic of the beryl in this particular pegmatite type, in which case it may be significant only within the Ishasha area or in areas where similar types of pegmatites occur.

7. Samples of the -190 micron fraction are representative of the soil for a radius of several feet from the sample point.

8. Background contents of Be in stream sediments vary between 1-3 p.p.m. The threshold value is 3 p.p.m.

9. Anomalous amounts of Be, up to 33 p.p.m., occur in the size-fractions of the stream sediment below the Waterfalls pegmatite and they may be detected at least 2000 feet downstream from the pegmatite, particularly in the -190 micron fraction which has a contrast of 3 at this point.

10. The bimodal distribution pattern of Be values in sediments is similar to that in soils and it continues downstream in the drainage; although the high Be contents of the coarse fractions of samples collected may be lost rather rapidly, a feature most likely due to the poor sample representivity inherent in these fractions unless large samples are taken for treatment before analysis.

11. The -190 micron fraction of anomalous stream sediment gives, in general, a reasonably representative sample of the sediment for a distance of up to 250 feet from a sample point. Representivity could possibly be improved by analysing the -100 micron fraction.

12. In general, spectrographic and gamma-neutron instrument analyses produce higher values than do the colorimetric methods. The contrasts between anomalous and background samples, however, probably do not differ appreciably between methods.

13. Sn is the only minor element of those studied which, in addition to Be, gives positive anomalies in soils and stream sediments related to beryl pegmatites. The contrast, however, is only 2-3, compared with that for Be of up to 20 (-190 micron fraction material).

14. There does not appear to be any correlation between base-exchange capacity and exchangeable-Be in the clay-fractions of soils and stream sediments.

15. The amount of readily-soluble Be in the clay-fraction of soils and stream sediments is, in general, 10-times as great as the exchangeable-Be content.

16. Groundwaters draining the two pegmatites at Ishasha contain detectable and anomalous amounts of Be, even after they are diluted on entering the stream system.

IV THE SECONDARY DISPERSION OF BERYLLIUM IN THE VICINITY OF BERYL PEGMATITES

Many complex factors may affect the secondary dispersion of an element in the lithosphere and the following discussion aims to consider those which control the dispersion of Be from beryl-pegmatites and to assess their relative importance.

The principal factors which govern the dispersion of an element in soils and stream sediments are:

(a) the primary mode of occurrence and distribution of the element in the bedrock;

(b) those which control the response of the bedrock to the processes of weathering and soil formation; and

(c) those which concern the movement of the products of weathering.

The consideration of these general factors in conjunction with the observed distribution of Be in soils, vegetation, stream sediments and stream waters as described in Section III, should serve to explain the presence and characteristics of Be anomalies in the vicinity of beryl pegmatites.

1. DISPERSION IN SOILS

A. Primary Mode of Occurrence

1. Beryllium minerals

Warner *et al.* (1959) list twenty-nine minerals in which Be is an essential constituent in amounts ranging from 1.8 to 36.0 per cent Be. Twenty of these minerals are silicates, demonstrating the oxyphile nature of the metal. Although minor amounts of other Be minerals may have been present in the pegmatites studied, the most important is undoubtedly beryl, the mineral from which virtually all the Be used in industry is obtained.

The chemical composition of beryl is $Be_3Al_2Si_6O_{18}$, or $3BeO.Al_2O_3.6SiO_2$. It belongs to the hexagonal crystal system (beryl type symmetry, Read, 1947). The SiO_4-tetrahedrons are linked together in rings of six with each tetrahedron sharing two of its oxygens with neighbouring tetrahedra. The Si_6O_{18}-rings are stacked one above another in columns, which are linked laterally by the Be-ions (in 4-co-ordination) and the Al-ions (in 6-co-ordination). Running through the stacks of rings there are thus empty "tunnels", parallel to the c-axis of the crystal, and within these "tunnels" water, helium and the ions of the alkaline metals may be accommodated.

The common hexagonal crystal form, hardness of 8, imperfect cleavage, uneven fracture and typical lustre, which has a finely textured sparkle, are the chief aids in field identification. These characteristics, however, are often not well developed, and it may then be difficult to distinguish the mineral from quartz or felspar.

Both specific gravity and refractive index increase with increase in alkali content and there is a corresponding drop in the Be content from 5.0 to 3.6 per cent. Beryl with specific gravity over the whole range from 2.66 to 2.90 may occur within a single pegmatite, each variety being related to a definite stage of mineral formation (high specific gravity in late stages) so that different generations of beryl are characteristic typomorphic minerals of the pegmatitic process (Beus, 1956a).

It is unlikely that the size-distribution of the beryl crystals in the primary occurrence is similar to that detected in the overburden during the investigation. In fact, it is possible that very little beryl with a particle-size less than 1 in. diameter occurs at the Bepe pegmatites (by observation, and according to Beus (1956a) for this pegmatite type). Also Gallagher (1959) and Gallagher and Hawkes (1960) consider that most of the beryl in the Mistress and Ishasha dykes, respectively, is medium grained ($\frac{1}{2}$-2 in. diameter), although larger crystals have been reported. It appears, therefore, that the finer beryl observed in the overburden is derived from the larger beryl crystals in the pegmatite.

An important factor controlling the disintegration of the beryl may be the extent to which intrinsic basal (perpendicular to the c-axis) and prismatic (parallel to the c-axis) partings occur within the crystals. Gallagher (personal communication) has detected inclusions in beryl crystals with which the partings may be associated. Evidence of such partings was, in fact, observed in crystals of the mineral at Bepe 2. On exposure to weathering, the partings may have a considerable influence on the grain-size distribution of beryl in the soil and stream sediment as discussed later.

2. Rock-forming minerals containing Be as a minor constituent

Most of the Be in the lithosphere is dispersed throughout the rock-forming minerals as a minor constituent, due to isomorphous substitution. The greater proportion occurs in felspars which often constitute the main volume of the rock mass. The highest concentrations, however, occur in the dark-coloured minerals, especially the micas.

Beus and Zahina (1956) give the following average figures for granite and its minerals:

Host	Be (p.p.m.)
Granite	8
Quartz	0.2
Plagioclase felspar	7
Dark minerals	32

The Be contents of the minerals of beryl-bearing granite pegmatites (Table 41) have been reported by Beus and Fedorchuk (1955).

TABLE 41

Be content of minerals from beryl-bearing granite pegmatites (after Beus and Fedorchuk, 1955)

Minerals	No. of samples	p.p.m. Be	
		Limits of content	Average content
Block quartz	5	0.5-4	2
Microcline-perthite	19	5-36	8
Albite	29	4-61	18
Muscovite	21	20-108	56
Lepidolite	9	16-126	49
Tourmaline, black	3	13-36	20

The amounts of Be in the rock-forming minerals at Bepe 2, Mistress and Ishasha are rather lower than those given by Beus and Fedorchuk. This, however, could be due to analytical errors involved when minerals are analysed by the colorimetric method. In any event, the amount involved is negligible in relation to the amount of Be contained in the pegmatites as the mineral beryl. Solodov (1958) describes a study in which he calculated that only 5.6 per cent of the Be in a pegmatite occurs in the dispersed state, whereas over 94 per cent is concentrated in beryl.

The isomorphous substitution of Be in silicate lattices is made possible by the similarity of the ionic radii of Be^{2+} (0.34 A°) and Si^{4+} (0.39A°). In order to maintain electrical neutrality within the structure, simultaneous substitution of another ion must take place. Beus (1956a) invokes energy considerations to show that Ti, Zr and the rare earths are the most important high-valence elements which substitute simultaneously with Be in silicates. Beus also considers it possible, in pegmatites enriched in rare-earth minerals, for the amount of Be dispersed in the felspars to equal or even exceed the lower limit of Be content given for commercial beryl deposits, i.e. 100 p.p.m. Be.

The Be in background rocks in the study areas is probably in the form of isomorphous Be substituted for Si in the rock-forming minerals. This applies particularly to granite and gneiss, in the overburden of which the metal was found to be concentrated in the fine fractions, especially in the clay, probably due to the retention of Be in the clay minerals produced from the weathered felspars and micas. There is, however, the possibility of the presence of disseminated fine beryl in the mica schists at Ishasha.

The mode of occurrence of Be dispersed in the wallrocks of pegmatites during their emplacement is not known. It may either be due to fine fine-grained disseminations of beryl or other Be minerals, or as Be incorporated in secondary minerals introduced during wallrock alteration. No extensive primary dispersions were observed in the study areas, however.

B. Weathering of Primary Minerals

1. Beryl

The ring structure of beryl, referred to on page 140, is extremely stable. The trace constitutents are readily accommodated in the channels and do not distort the structure or weaken the chemical bonds. It is therefore difficult for ions to leave the structure to allow disintegration by chemical means, and the diminution of large beryl crystals to smaller fragments is possibly largely due to physical processes. The mechanism may be one in which water and solid materials, such as iron oxides and kaolin (derived from micas and felspars) penetrate the crystals through openings caused by weaknesses along the intrinsic basal and prismatic partings (see page 141). Subsequent alternate wetting and drying may cause expansion and contraction of the extraneous materials to further weaken the fractures until ultimately the crystals disintegrate to fragments, the size of which is controlled by the original fracture pattern. Extraneous red-brown iron oxides and white powdery material (probably kaolin) was commonly noted along fractures in beryl crystals from each of the present study areas.

Kerr (1946) has reported the occurrence of a pseudomorph of kaolin after caesium-bearing beryl. Infiltration of the kaolinite through the beryl appears to have taken place by direct replacement, first along incipient fractures, followed later by mass invasion. The penetration of solutions was aided by a widespread distribution of microscopic cavities which provided points of weakness where kaolinisation progressed more rapidly than in more solid parts of the crystal. Analysis of the kaolinite indicated that the Be was carried out of the system and did not remain with this material.

The replacement was possibly due to the action of hydrothermal solutions rather than to supergene weathering, and it seems likely that physical processes are usually more important than chemical processes in the weathering of beryl. The presence of the microscopic cavities referred to by Kerr could, of course, assist in physical disintegration of the mineral.

If the chemical weathering of beryl is insignificant the size-distribution of the mineral in the weathered residuum would be controlled essentially by the original grain-size, the presence or absence of intrinsic partings combined with inclusions or cavities, and physical abrasion during weathering. At Bepe 2 the Be content of size-fractions, presumably mostly in the form of beryl, decreases more markedly with particle-size than at Mistress, while at Ishasha Be is concentrated in two ranges of particle-size (c.f. Figs. 11, 26 and 34). Each type of beryl distribution may be a characteristic of the particular pegmatite type (of the Beus classification) in which it occurs. The pattern of size-distribution of the beryl in the overburden will have no bearing, however, on the mineability of the mineral still in situ in the pegmatite.

Probably the most striking feature in anomalous soils and sediments is the uniformity of the grainsize distribution of Be even in samples which are removed for considerable distances from the bedrock source. Nowhere is this more apparent than at Bepe 4 where the high values in the coarse fractions of the soil persist for at least 900 feet from the dyke, and at Ishasha where the characteristic bimodal pattern persists throughout the anomalous soil and into the stream sediments in which, however, only the anomalous values in the fine fractions are detected 2,000 feet downstream. This feature testifies strongly to the chemical and physical resistance of beryl to the soil-forming and weathering processes generally.

The possibility that beryl weathers chemically must not be disregarded. The Be content of felspars and micas, 1.5-7 p.p.m. and 7-60 p.p.m. respectively, may not entirely account for the high values of up to 25 p.p.m. Be in the clay fraction of anomalous soils. Although these values could be due, in part, to residual concentration, the effect of which cannot be evaluated as the amount of soluble silica removed from the system cannot be determined, another source of Be in the clay could be beryl. Mechanical comminution to this degree is not considered possible within the soil environment. Futhermore, it seems likely that if the major part of the Be content of the clay fraction occurred as beryl, then the readily-soluble Be values (Table 34) would be much lower than those actually observed. Chemical breakdown of beryl, however, could explain the increase of readily-soluble Be from 12.5 per cent in the lower sub-soil to 30 per cent in the top-soil, (profile P3, Table 34) although rather higher contents of exchangeable-Be would be expected also. In addition minor solution and reprecipitation of Be from beryl could account for the rise in Be content in the fine fractions of subsoil samples at Bepe 2 and Bepe 4 (Figs. 11E and 24 respectively).

Jackson and Sherman (1953) emphasise the importance of particle-size in considering the chemical weathering of minerals, viz:- as the particle-size decreases and the specific surface increases the mineral becomes more susceptible to chemical attack. The result is that there is a minimum size at which a mineral of a given stability can exist under a given intensity and period of weathering. These authors also consider that minerals which are resistant to chemical weathering tend to persist in the finer fractions. However there is a certain size, called the 'extinction factor', below which a mineral cannot exist because it becomes susceptible to chemical weathering.

Nothing is known concerning the extinction factor for beryl, although it is interesting to note that Jackson and Sherman's figure for quartz is 2 microns under tropical conditions. In any event, it seems unlikely that much of the primary beryl has so small a grain-size, and the resistance of coarser material to physical comminution is well illustrated by the fact that the size distribution of Be is retained throughout the soil profile (see Fig. 11C).

2. <u>Rock-forming minerals</u>

Field observations indicated that there is relatively little weathering of the rock-forming minerals whilst they are still incorporated in the bedrock. The potassium felspar, microcline-perthite, is probably the mineral most affected by the penetration of water along the fracture and cleavage planes, resulting in softening of the material which, however, retains its original form and appearance. Mechanical disintegration to sand-size is occasionally observed but there is little evidence of clay formation indicative of extensive chemical weathering. Iron-oxide coatings are prevalent along fractures and they increase with the degree of weathering. Any release of Be from the rock-forming minerals whilst they remain in place in the bedrock would be negligible.

There is, however, an abrupt increase in the rate of weathering on passing from the bedrock up into the overburden. The fact that the gain-size distribution remains generally uniform from the surface down to the deepest sample in the overburden suggests that the size-distribution pattern in the soil is inherited from the underlying bedrock source, at least insofar as the mineral beryl is concerned. In the soil, any Be contained within a mineral susceptible to weathering is liable to be released and more or less dispersed according to conditions in the local environment. This is the case in background soils, particularly those over granite, where there is a marked tendency for Be to concentrate in the fine fractions.

The pH of soil solutions in a humid siliceous environment is usually within the range 4.5-7.5 at which aluminium is liberated from the decomposing minerals as the positively charged colloidal hydroxide. According to Hazel (1938) and Barshad (1955) the Al-hydroxide then reacts with negatively charged colloidal silica to form clay minerals, of kaolin type in tropical soils.

Britton (1956) gives the pH values for hydroxide precipitation from dilute solutions as 4.1 for Al and 5.7 for Be. Thus it is possible that in soil solutions with pH below 5.7 Be will remain in the form of the soluble cation, whereas at higher pH values the positively charged colloidal Be-hydroxide may accompany Al-hydroxide in the formation of clay minerals. It must be emphasised, however, that Britton's values refer to pure hydroxide solutions only, and that in the soil environment the hydrolysis pH may vary considerably from the figures given.

Another mechanism which could play an important part in the removal of Be from soil solutions is that of co-precipitation.

Griffiths (personal communication) considers that Be may be quantitatively stripped from water by hydrolysis of Fe and the precipitation of hydrous ferric oxide, and Be has been found enriched in alumina precipitates from stream waters. Also Laitinen and Kivalo (1952) studied the collection of Be on hydrous ferric oxide and found that 50 per cent of the element in solution could be collected at pH 5, and that it could all be collected at pH 6 and above.

Depending on the prevailing pH, therefore, trace amounts of Be released from weathering felspars and micas (and perhaps beryl; see above) will either be removed from the system, be adsorbed on surfaces of clay-size particles, be co-precipitated with ferric hydroxides, or be incorporated within clay mineral lattices. Be in the latter form would be much more firmly held than that which is adsorbed or co-precipitated. Since only less than 3 per cent of the total Be in soil-clay was found to be exchangeable as compared to up to 30 per cent that was readily soluble (Table 30), it would appear that by far the greater amount of the Be liberated by decomposition of felspar (and mica) is incorporated in the secondary clay mineral lattices or co-precipitated with iron hydroxides.

C. Chemical Dispersion in Soil

According to relative mineral stabilities the dispersion of an element in the zone of weathering may be accomplished either by chemical or mechanical processes or a combination of both.

Whereas chemical dispersion may not be a predominant process in the formation of soil anomalies, it is effective in controlling the dispersion of Be liberated by the weathering of the common rock-forming minerals derived from pegmatite and country rock.

1. Solution and precipitation

By virtue of the stability of beryl, solution and precipitation of Be in the percolating soil- or ground-waters probably does not contribute to any great extent in the redistribution of anomalous metal in the areas studied.

The relatively small amounts of Be released from the weathering felspars and micas (and perhaps beryl), whether in the form of the cation or positively charged colloidal hydroxide, would possibly not travel any great distance downward or laterally before becoming attached to negatively charged colloids. Only in environments with very low pH can the ion be particularly mobile.

Soil pH at Ishasha ranges from 4.8 to 6.5, averaging about 5.4 (Table 42). Whether the mobility of Be would be affected by pH variations within this range is not known. However the

TABLE 42

pH values of soils, Ishasha

Profile											
P2		P3		S2		S4		S5		G1	
Depth (in.)	pH	Depth (ins.)	pH	Depth (in.)	pH	Depth (in.)	pH	Depth (in.)	pH	Depth (in.)	pH
0-2	6.5	0-3	5.4	0-3	5.1	0-2	5.8	0-3	5.5	3	6.0
8	5.6	8	5.0	8	5.1	6	5.1	8	5.2	18	6.0
14	4.8	24	5.3	30	5.1	27	5.3	18	5.0	45	6.4
24	5.2			66	5.1	50	5.2	26	5.0		
46	6.3										

range does cover the value of 5.7 given by Britton as the pH of hydrolysis of Be, but the limitations of this figure, as previously mentioned, must be taken into account.

In this connection, Hem (1959) considers that adsorption of Be by naturally occurring minerals is an important cause of the low values in water, since such adsorption seems to proceed effectively at pH levels common in natural waters. He cites the work of Thatcher and Singman who found that at pH 3.5 there was no adsorption of Be from water by glass or plastic containers over a three month period, whereas at pH 7-8 there was considerable adsorption. Merrill *et al.* (1960) also discuss the adsorption of Be on glass. They consider that adsorption is negligible at pH 4.0, rising to complete adsorption at pH 7.

Very tentatively, the dispersion of soluble Be in soils at Bepe, where the pH is 6.0-6.8, is possibly very limited, but it may be rather greater at Ishasha where lower pH values prevail, particularly in the freely-drained soils.

2. Biochemical factors

The overall effect of the absorption of an element by vegetation is to raise the metal from the lower soil horizons in the nutrient uptake and to return the metal to the surface where the plant material dies and decays. The effect should be most noticeable at Ishasha where there is thick forest vegetation and a mat of decaying material several inches thick at the top of all soil profiles. There is, however, no apparent concentration of Be in the surface soil either at Ishasha or at Bepe (Figs. 10 and 33). It is assumed, therefore, that biochemical factors play a very minor role in the distribution of Be in soils, and that there is no direct association between Be and organic carbon.

This conclusion is supported by analyses of the ash of leaves and twigs of certain common trees (Tables 21 and 26) which indicate that only insignificant amounts of Be are absorbed by these species. Furthermore, there is no striking correlation between the Be content of the vegetation and the underlying soil in the areas examined. Finally, that portion of the total Be content that is most likely to be readily available to the vegetation is the readily-soluble Be in the clay fraction. The data indicate, however, that in anomalous soil the clays contain only a minor proportion of the Be present in the total soil and that only a small part of this is readily soluble. A rather greater proportion of the total metal may be available to the vegetation in background soils.

These conclusions, based on a limited number of observations, are necessarily provisional even when applied to the present study areas. Under different conditions, positive correlations have, in fact, been observed between the Be content of vegetation and the underlying soil. For example, Zalashkova _et al._ (1958) have used the biogeochemical occurrence of Be in prospecting for beryl pegmatites, and they obtained up to 39 p.p.m. Be in the ash of alder leaves, against background values of less than 3 p.p.m. Furthermore, samples with organic origin containing extremely large amounts of Be have been recorded in the literature. Thus, Goldschmidt (1954) reports contents of up to 8,000 p.p.m. Be in the ash of certain coals, although the normal content of coal ash is 4-10 p.p.m.

D. Mechanical Dispersion in Soil

By virtue of the chemical stability of beryl, mechanical processes are of far greater importance than chemical action in the formation of Be soil anomalies.

In the study areas, the two principal mechanical dispersing agents are soil creep and sheet wash.

Soil creep is particularly effective under the conditions of strong relief and scant vegetation that exist at the Mistress Claims. At Ishasha the dense vegetation tends to hold the soil in place but would not prevent soil creep on the steep slopes which in places exceed 40 degrees. The topography at Bepe is much less pronounced for here the land surface is mature and there has undoubtedly been adequate time for gravitational movement of the overburden.

Surface sheet wash takes place during periods of heavy rainfall at Bepe and at Mistress, but may be relatively limited at Ishasha even during heavy falls of rain because of the forest canopy and dense undergrowth.

The two agents of soil creep and sheet wash combine to transport anomalous material downslope where it forms the topsoil and mixes with the barren soil derived from the country-rock. The proportion of admixed anomalous soil naturally decreases with depth from the surface.

The distribution of Be in the various size-fractions of anomalous and background soils, together with their mechanical composition, has a considerable bearing on the width and magnitude of the anomalies detected in the different size-fractions. Thus, in schist areas the country rock weathers to a clay-rich overburden with a high proportion of fine material (Table 43), causing rapid dilution of the anomalous values in the fine size-fraction on passing downslope from the dyke (Bepe 2, Fig. 11).

TABLE 43

Content of -80 micron fraction in soils, Bepe 2

Distance downslope from pegmatite (ft)	Per cent -80 micron fraction	
	Topsoil	Subsoil
On pegmatite (10N, felspar zone)	41	38
On pegmatite (109S, beryl zone)	41	34
40 (150 N)	51	70
125 (300S)	68	80
1825 (2000S)	80	78

Granite and gneiss soils, on the other hand, although having a mechanical composition similar to pegmatite soils, carry a relatively high background Be content in the clay fraction. For this reason, the anomaly in the fine fraction is again less in width than that detected in the coarse fraction. This is illustrated in Traverse 0 at Bepe 4 where the high contrasts in the coarse fractions extend for at least 900 feet downslope from the pegmatite (Fig. 24) whereas high background values in the fine fractions, due to nearby granite, restrict the anomalous values to a distance of 500 feet from the dyke (Fig. 23).

The persistence of the size-distribution of beryl even after transport for these distances in the overburden stresses again the great mechanical and chemical resistance of the mineral in the zone of weathering.

The above conclusions regarding the distribution of Be in soils may apply only to the areas studied, and under other weathering conditions it may be entirely different. The nature of the Be mineral is also of paramount importance in this connection, particularly with respect to those minerals which weather readily, such as helvite.

E. The Association of Other Elements with Beryllium

Spectrographic analysis shows that a number of elements give soil anomalies in addition to Be at both the Bepe 2 and Waterfalls pegmatites:

Element	Contrast of anomaly in relation to that of Be anomaly	
	Bepe 2	Waterfalls
Sn	Less	Less
Li	Similar	("Negative" anomaly)
Rb	Greater	(No anomaly)
Sr	Less	(No anomaly)
Ba	Less	(No anomaly)

The pegmatite minerals in which each of these elements is likely to occur are listed in Table 44.

TABLE 44

The occurrence of Sn, Li, Rb, Sr and Ba in pegmatites

Element	Mineral	p.p.m.*
Sn	Cassiterite (SnO_2)	
	Plagioclase felspars	50
	Micas (e.g. biotite)	300
Li	Amblygonite Spodumene Lepidolite } Li an essential constituent	
	Potash felspars	5
	Biotite	3500
	Muscovite	2000
	Tourmaline	65
	Beryl	8000
Rb	Potash felspars	30000
	Biotite	av. 5300
	Lepidolite	av.12000
	Muscovite	av. 1300
	Beryl	
Sr	Plagioclase felspar	10000
	Potash felspar	340
	Biotite	4000
Ba	Potash felspar	170
	Biotite	
	Muscovite	90000

*Maximum contents reported in the literature, unless average stated.
(Goldschmidt, 1954; Rankama and Sahama, 1949).

Sn enters silicate structures only to a limited degree, the excess separating out as cassiterite. Data obtained at Ishasha indicate that, on weathering, the Sn occurs mainly in the fine fractions, particularly the clay, of both background and anomalous soils (Table 33). This may indicate that cassiterite is not the predominant form of Sn in this pegmatite and that the metal detected has been precipitated after being liberated from felspars on weathering. The size-fraction in which Sn occurs in the soil at Bepe 2 was not determined. It is unlikely, however, that Sn could be used to locate beryl pegmatites because it is improbable that there is a general relationship between the presence of Sn and the occurrence of beryl.

Felspars are usually very poor in Li but the metal is enriched in the micas, in which it replaces Al, Mg and Fe. Li is often as strongly enriched in granite pegmatites that it forms independent minerals such as amblygonite, spodumene and lepidolite. Spodumene occurs in the Bepe 2 dyke and the Li anomaly at this prospect could be due to metal derived from this source. At Ishasha, however, Li minerals have not been reported and it appears that the metal is essentially associated with the mica of the schist country rock since there is only a "negative" anomaly over the pegmatite. Thus it appears that Li may be used to locate beryl pegmatites only if it has been ascertained previously that in the pegmatites sought there is an association between Li minerals and beryl, and that appreciable amounts of the metal do not occur in the country rocks.

Rb, Sr, and Ba do not form independent minerals in pegmatites. Rb, and Ba substitute for K in potash felspars and micas, whereas Sr may replace Ca in plagioclases in addition to K in potash felspars and micas. Thus the anomalies indicated for these metals at Bepe 2 are consistent with the fact that the principal felspar is the potash variety. At Ishasha, where either a negative anomaly or no definite trend is shown, it is probable that plagioclase felspars may predominate and that the content of Sr, Ba and Rb in the pegmatite is similar or less that the content in the schist country rock.

2. DISPERSION IN DRAINAGE

A. Dispersion Mechanisms

During the course of erosion the products of weathering may be dispersed in the surface drainage system in three principal forms:-

(a) as soluble salts in the stream water,

(b) as precipitates of one form or another in the stream-bed sediment, and

(c) as constituents that were present in the overburden before the latter was eroded to form the clastic stream sediments.

The relative importance of these materials in the dispersion of Be is considered below.

1. Dispersion in stream water

By virtue of the chemical resistance of beryl, the saline dispersion of Be was not investigated in nearly the same detail as was the dispersion of clastic products of weathering. In addition, prospecting by water analysis is not attractive from the point of view of (a) the analytical difficulty of determining the minute concentrations involved, and (b) the effect of the many factors that can influence the concentrations, notably variations in pH, rainfall and so on.

The solubility of Be and the stability of its solutions in the zone of weathering have already been discussed (page 149). Briefly, within the pH range encountered in the present study areas it appears that only a minor proportion of the total Be in the weathering complex is transported in solution and, furthermore, it is unlikely that these solutions would be stable. These conclusions are particularly applicable as regards the dispersion of Be from the beryl-pegmatites that were studied, but a higher proportion of the background Be content may be dispersed in solution. Even here, however, it is unlikely that more than a minute fraction remains in solution for any appreciable distance.

The limited data available are consistent with these considerations. In background streams the Be content does not appear to exceed 0.0005 p.p.m. (Table 40). Even the stream that crosses the Waterfalls pegmatite at Ishasha does not contain more than 0.001 p.p.m. Be, and the only markedly anomalous water sample was collected in the tributary draining the Ishasha mine. This tributary carried 0.02 p.p.m. Be but whether this concentration is affected by the presence of the mine workings is not known. In any event the presence of this anomalous tributary, which is only small relative to the Kagoma River, could not be detected in the main stream below the confluence.

2. Precipitation on stream sediment

For many soluble metals, precipitation on the stream sediment can be an important factor in the development of drainage anomalies. The development of such anomalies in the case of Be is clearly restricted by the rather limited dispersion of this element in the surface water, despite the fact that precipitation would quite probably take place under the conditions prevailing in the study areas (page 151).

Again the available data support this contention. Thus there is little evidence of saline precipitation in the streams examined. However, any precipitated metal would be expected to be readily-soluble and, in fact, as much as 40-50 per cent of the total Be content of the clay fraction of stream sediments at Ishasha in both anomalous and background samples (Table 39) was extracted with cold dilute acid. It is interesting to note that X-ray investigations of the clay fractions (by M. J. Gallagher) revealed that appreciable amounts of secondary iron oxides are associated with the clay minerals and as discussed previously (page 150), the readily soluble Be may have been co-precipitated with the iron compounds.

3. Erosion and transport of clastic stream sediment

The development of drainage dispersion trains resulting from the erosion of anomalous soil was studied in considerably greater detail. The main reason for so doing lay in the fact that Be liberated from beryl-pegmatites during weathering would most likely reamin in the form of the resistant mineral beryl, even after erosion and transport in the surface drainage system.

In all cases studied, stream sediment anomalies were only observed where anomalous residual or colluvial soil was undergoing active erosion. It follows, therefore, that a drainage sediment anomaly can only be expected where a juvenile stream course cuts across a soil anomaly related to a pegmatite occurrence.

That the sediment anomaly is formed by erosion of anomalous soil is confirmed by the fact that the pattern of distribution of Be in the different size-fractions remains the same in both the soil and the corresponding stream sediment. Nowhere is this more clearly demonstrated than at Ishasha where a bimodal Be pattern is evident in the size-distributions of both media; a similar correspondence was also observed at Mistress.

B. Magnitude and Persistence of Anomalies

From the prospecting point of view, the two principal characteristics of drainage anomalies are the magnitude or contrast at the source and the persistence of anomalous values downstream. When the dispersion is predominantly mechanical, as in the present case, contrast is related to the nature of the mineralization and its position with respect to the stream channel, whereas persistence depends upon the extent to which the anomalous material is subject to dilution by barren sediment.

1. Anomaly contrast

In the first instance, anomaly contrast is determined by the rate at which anomalous metal is supplied to the drainage. Small high-grade deposits may contribute at the same rate as large low-grade deposits. There is, therefore, no means of differentiating between variations of grade and size of deposits if the contributions of anomalous metal to the sediments are of the same order. Only if all other conditions are comparable, will there be a degree of correlation between the grade of a deposit and the tenor of its associated anomaly.

In general, the closer the pegmatite source lies to the stream the greater will be the anomaly contrast. This, of course, arises from the fact that the soil anomaly — which is the source of the sediment anomaly — decays with distance from the pegmatite contact. The rate of decay for the different size-fractions of the soil will also depend on the relative mechanical compositions of the pegmatite and country rock soils and their relative metal contents. Thus, admixture with clay-rich schist soils or relatively high-Be background granite soils can both result in a relatively high rate of dilution of Be in the fine fraction. These features are reflected in the stream sediment. Nevertheless, it must be emphasised that very large samples and fine grinding are essential if a representative contrast is to be obtained with coarse-grained fractions.

Peak anomaly contrast is also affected by the degree of dilution encountered when the anomalous soil is eroded into the stream channel. For this reason, other factors being equal, maximum contrast will be obtained where the metal is entering at the headwaters of the stream, whereas metal fed in at the same rate further downstream will be subject to immediate dilution on joining the existing barren load. This feature is illustrated in Table 45 where it is shown that the drop in values between the soil and sediment is much greater for the Waterfalls dyke, which lies at least 2000 feet below the headwaters, as compared to the Mistress values where the entire headwater area is anomalous.

TABLE 45

Mean Be content of size-fractions of colluvial soil and corresponding stream sediment at the Waterfalls and Mistress pegmatites

Size-fraction (microns)	Pegmatite			
	Waterfalls (Ishasha, Uganda)		Mistress (Rhodesia)	
	Soil p.p.m. Be	Sediment p.p.m. Be	Soil p.p.m. Be	Sediment p.p.m. Be
900-2000	140	33	200	350
470-900	60	10	125	220
190-470	40	6	100	60
100-190	65	10	60	30
80-100	90	18	45	25
20-80	180	32	48	25
2-20	140	29	60	10
0-2	20	16	5	

2. Persistence of anomalies

Colluvial bank soils composed of barren valley-slope soil result in much greater dilution than do alluvial banks composed of material derived from the same source as the present-day stream sediment. Except at the confluence of the stream draining the pegmatite with the Mabfeni River at Mistress, only colluvial banks were encountered in the present study areas. Even so, the drainage trains were detectable for 3000 and 2000 feet downstream from the pegmatites at Mistress and Ishasha, respectively. Longer drainage trains could be expected in areas where the streams flow through their own alluvium.

As regards the possiblity of comminution of beryl during the course of stream transport, it is interesting to note that Warner _et al._ (1959) give beryl an abrasion resistance value of 270-465 in comparison with that of quartz of 245 (relative to hematite = 100). Furthermore Kuenen (1959) has carried out experiments demonstrating that there is negligible abrasion of sand-size quartz and felspar grains as a result of alluvial transport. These considerations indicate that, with the possible exception of large fragments of beryl, there is little likelihood of comminution of beryl on passing downstream from the point of entry of anomalous soil derived from a weathering beryl-pegmatite. This conclusion is consistent with the size-fraction data at Mistress, where the sediment anomaly remains in favour of the coarse fractions throughout the course of the stream (Table 28). At Ishasha, however, the coarse fraction anomaly is far less persistent than that in the fine fraction, but this is believed to be due to the fact that only small samples of the coarse sediment, which could not have been representative, were treated. The reason for the greater persistence of the fine-fraction anomaly at Ishasha, as compared to Mistress, is due to the original difference in contrast in the soil that provides the source material for the sediment.

The persistence of anomalies in the different size-fractions is naturally dependent on the magnitude of the local background values for these fractions relative to their peak values at the anomaly source. Thus, at both Mistress and Ishasha, the background for the finer fractions is relatively high. This helps to explain the poor persistence of the fine-fraction anomaly at Mistress. However, at Ishasha this is off-set by the high tenor of the anomalous fine fraction material.

Whereas dilution by bank erosion is progressive, confluence with barren streams usually causes an abrupt decrease in anomalous values. In general terms, the extent of the dilution is proportional to the respective magnitudes of the anomalous and barren catchment areas. This effect is evident at the confluence of the two branches of the Kagoma River, at Ishasha, which are comparable in size (Fig. 40). Anomalous Be values of 10-15 p.p.m. occur in the -190 micron fraction of sediments in the East Branch, and low contents of 3-4 p.p.m. occur in the South Branch. Below the confluence the values are 5-7 p.p.m. Be.

Although no data are available, the effect of dilution of anomalies in the different size-fractions of the sediment will naturally depend on the mechanical composition of the barren diluent. Thus, an anomaly in the coarse fraction will obviously not be affected by the addition of barren clay, and *vice versa*. In point of fact, barren and anomalous sediment were invariably similar in mechanical composition within each area where size-analysis examinations were carried out. It is, however, important to stress that the data are not necessarily applicable to other areas where different conditions prevail.

V. SUMMARY AND CONCLUSIONS

The following general conclusions are based on a study of the distribution of Be, with particular reference to soils and stream sediment, in the vicinity of beryl-pegmatites at the Bepe and Mistress Claims in S. Rhodesia and at Ishasha in S.W. Uganda.

Before summarising the general features of the Be anomalies detected in these areas it is interesting to note that each of the aforementioned pegmatites falls into a different group of the Beus classification. According to Beus, recognition of the different types of beryl-pegmatite is important in that some do not normally contain commercial concentrations of the mineral.

In the pegmatites examined the predominant Be-bearing mineral is beryl. The Be contents recorded in the rock-forming minerals were: quartz, 0.25-1 p.p.m.; potash felspar, 1-3 p.p.m.; plagioclase, 6-7 p.p.m.; and muscovite, 7-60 p.p.m. Examination of the wallrock at the Bepe 2 dyke indicated that primary dispersion of Be is limited to 12 feet or less from the contact.

1. SUMMARY

1. Rapid colorimetric analysis using the Berillon II reaction demonstrated the presence of Be anomalies in

soil and stream sediment in the vicinity of beryl-pegmatites.

2. Under favourable conditions, soil anomalies were detectable up to 900 feet downslope from a dyke where residual overburden ranged from 1-8 feet in depth.

3. Background Be values in soils vary with the underlying rock type. The following background contents were established: granite and gneiss, 2-4 p.p.m. Be; schist, 1 p.p.m. at Bepe and 1-5 p.p.m. at Ishasha. In general the highest Be concentrations occur in the finest fractions of granite and gneiss soils, whereas there is no distinct trend of Be distribution between size-fractions of schist soils.

4. Greatest anomaly contrasts, up to 1000, are obtained with coarse-fractions, whereas fine-fraction contrasts seldom exceed 100.

5. Homogeneous anomalies are obtained by analysing sieved fine material (-190 micron fraction), without crushing. In the case of coarse-fractions homogeneity is only achieved by grinding very large samples before analysis.

6. Peak anomaly values are related to zoning of beryl in the underlying pegmatite.

7. Anomalous drainage trains are detectable in the sediment of actively eroding streams near beryl-pegmatites.

8. Anomalous Be values in stream sediments immediately below the dykes were as high as 350 p.p.m. for the 900-2000 micron fraction at Mistress, and more than 30 p.p.m. in the 900-2000 and 20-80 micron fractions at Ishasha.

9. The best anomaly in stream sediment occurred in the coarse-fraction (190-2000 microns) at Mistress, but at Ishasha it was in the 2-80 micron fraction. In each case the anomaly persisted downstream for at least 2000-3000 feet before decaying to background values of 1 p.p.m. and 3 p.p.m. respectively. Again large samples and grinding are necessary for homogeneity in coarse-fraction values.

10. Limited stream water sampling indicated only weak anomalies of 0.001 p.p.m. Be in the local drainage, compared with background values of 0.0005 p.p.m. The only high content of 0.02 p.p.m. Be was detected in the small tributary draining the Ishasha mine workings.

11. Limited sampling of vegetation showed no correlation between the Be content of common tree species and the proximity to mineralisation.

12. The anomalous Be dispersion patterns are formed primarily by the mechanical dispersion of beryl from the dykes and are consistent with the stability of beryl in the zone of weathering.

13. Each pegmatite appears to be characterised by a particular grain-size pattern of beryl which persists almost unchanged throughout the soil profile. This leads to the conclusion that the distribution of beryl in the soil reflects either the grain-size or physical parting within the beryl crystals in the bedrock.

14. The grain-size pattern of beryl in the soil persists into the associated stream sediment, indicating (a) that the sediment anomaly is derived by erosion from anomalous soil, and (b) that the effect of abrasion during stream transport is negligible, insofar as sand-size and smaller grain-sizes are concerned.

15. Chemical dispersion of Be is probably only effected by the metal liberated from weathering felspars and micas, although there may be some minor chemical weathering of beryl. It probably accounts for much of the metal content of the clay fraction wherein it is rapidly incorporated under the conditions of relative high pH which prevail in the study areas. Chemical dispersion may be important in the formation of the background Be patterns.

16. Field gamma-neutron instrument readings, by K. C. Burke, disclosed generally similar patterns to those obtained with the colorimetric method, but greater fluctuation and higher values reflected the erratic distribution of coarse fragments of beryl in the overburden.

17. Spectrographic analyses of soil and sediment samples indicated that Sn is the only other metal which gave an anomaly at each of the Bepe 2 and Waterfalls pegmatites. Li, Rb, Sr and Ba also gave anomalies at Bepe 2. In general the anomalies have a similar width to those for Be but the contrast is less. There is, however, no likely connection between the anomalous amounts of these elements and the occurrence of beryl in the pegmatites.

2. PROVISIONAL PROSPECTING PROCEDURES

Although the results of the present study provide the information upon which to base stream sediment and soil sampling procedures that would be applicable in the areas examined, each new area will usually present its own problems. Consequently, it is essential not only to establish the applicability of the geochemical approach in each case but also to weigh the relative merits of all the different prospecting techniques that are available. The routine sediment and soil sampling procedures outlined below, therefore, may be used as a guide and illustration, but it must be realised that a preliminary orientation study under local conditions is a mandatory pre-requisite to effective prospecting.

Exploration problems normally fall into one of two classes: reconnaissance surveys and detailed surveys. The former includes all those operations aimed at appraising the mineral potential of a given area, with a view to eliminating barren ground and focussing attention on those parts of the area meriting further examination. Detailed surveys, on the other hand, refer to the examination of ground that is already known to be of interest, with the object of pin-pointing the location of the bedrock metal source preparatory to drilling or applying other means of sub-surface examination. Since quite large areas are often involved in reconnaissance, the technique should be such that it can be operated on a low cost per unit area basis. Detailed surveys are usually applied in small areas, allowing a high cost per unit area.

For these reasons the large targets used in reconnaissance should be large in relation to the orebody that is sought, while for detailed surveys it is preferable to have a smaller target closely related to the bedrock metal source.

The techniques outlined below refer only to areas where the overburden is dominantly residual. It is, in fact, doubtful whether these methods could be applied where the overburden is transported, although further research would be necessary to investigate this point.

A. Reconnaissance Surveys

The present study has indicated that, given a reasonable drainage pattern, it may be possible to use the analysis of stream sediments for Be as an aid to reconnaissance surveys for this metal.

In some areas it may be possible even to carry out large-scale reconnaissance by soil sampling, providing topographic and overburden conditions are such that broad soil anomalies may be expected.

1. Drainage surveys

Orientation for drainage reconnaissance techniques should aim at determining:

(a) The local and regional background values;

(b) The length and persistence of anomalies related to deposits of significant mineralization;

(c) The optimum sample weight, size-fraction, and sample preparation procedure.

Ideally the orientation should be carried out in the vicinity of known but undisturbed mineralization. Although the precise details will undoubtedly vary from area to area, the results obtained at Bepe, Mistress and Ishasha indicate that the following routine technique would be applicable under these and similar conditions elsewhere.

1. Collect stream sediment samples in duplicate at 1000 feet intervals, including samples from above the confluences of all tributaries. At each point attempt to collect comparable coarse-sand-silt samples. The weight required to give a representative sample will depend on the results of

the orientation survey, but if the -190 micron fraction (-80 mesh) can be used, 50-100g of sediment will normally provide an adequate amount of sieved material for analysis.

Avoid collecting samples which may contain locally collapsed bank soils. Omit sampling in streams where the catchment area exceeds 5 square miles. (Samples are best collected by means of a deep container such as an enamel mug, and placed in special water-resistant Kraft paper envelopes).

2. The samples may be dried in their containers either by air-drying or in an improvised low-temperature oven according to local climatic conditions.

3. Sample preparation depends on the selected optimum grain-size fraction. For samples of -80 mesh or finer, it is only necessary to lightly break up the aggregate in a porcelain pestle and mortar before sieving. Coarser fractions must be finely ground before analysis; it is for this reason, and the fact that large samples are required, that it is preferable, if possible, to use the fine fraction.

4. The samples may then be analysed by any one of the berillon colorimetric methods. Although satisfactory results may be obtained by any of the procedures given in the Appendices, it is considered that the buffer method is probably the best due to its relative simplicity and slightly higher productivity.

5. After plotting the data on the drainage map, anomalous indications should be followed up with more detailed sediment sampling at close intervals, with a view to determining the point of entry of the metal into the drainage system.

6. At the cut-off, bank and base-of-slope soil traverses may assist in determining the direction to the bedrock metal source. After delimiting the area of interest, further detailed surveys by geological and geochemical soil methods may be used to pin-point the anomaly source.

2. Reconnaissance soil surveys

The applicability of reconnaissance soil surveys will depend, in general, on the magnitude of the soil anomalies and the economics of the operation. Routine techniques would normally be similar to those described below for detailed surveys.

B. Detailed Soil Surveys

As for reconnaissance, a preliminary orientation survey is again essential. The importance of collecting pertinent samples, particularly from background, during the orientation survey cannot be stressed too greatly, in order that the correct background and threshold values will be obtained, and to avoid errors in interpretation.

Sampling over a known pegmatite occurring under conditions that are typical of the exploration area, should be carried out with a view to determining:

(a) The magnitude and extent of anomalies related to significant deposits;

(b) The optimum sampling depth, sample weight and size-fraction for analysis.

This is best done by collecting a series of soil profile samples at a number of points across known mineralization, in a manner similar to that described in Section III.

The sample pattern for prospecting purposes should be such that at least two traverses cross an anomaly related to the dyke that is of interest, and the sample interval should ensure that at least three samples will fall within any significant anomaly. In flat to moderately hilly terrain the sampling grid should be laid out in a series of parallel traverses crossing the anticipated strike. If the strike is not known it would be necessary to use a modified square sampling grid. In rugged terrain, base-of-slope and ridge-crest traversing is often more convenient, supplemented, if necessary, by intermediate contour traverses.

The following procedures could be recommended for prospecting in areas where conditions are similar to those at Bepe, Mistress and Ishasha; parallel traversing would be recommended at Bepe and Mistress, but ridge-crest and base-of-slope traversing would be more appropriate in the hilly country at Ishasha.

1. Collect soil samples, at the depth and of the weight indicated by the orientation survey, at 100-200 feet intervals in suitably spaced traverses. Under the relatively flat-lying conditions at Bepe where parallel traverses are possible, a suitable interval would probably be in the order of 500 feet, giving 400-800 samples per square mile.
2. Drying, preparation and analysis procedures for soil samples are similar to those described for stream sediments.
3. After plotting the data, follow up anomalous indications by more detailed sampling at closer intervals, in order to determine the shape and extent of the anomaly.
4. Finally, close sampling at 5 feet intervals on lines across the axis of the anomaly, about 50 feet apart, may serve to pin-point the positions of the principal beryl zones, and serve as a guide to pitting or trenching.

GENERAL CONCLUSION

The results of this study indicate that geochemical methods can undoubtedly assist in exploration for Be ores concealed beneath residual overburden. In this connection it is important to stress that the field gamma-neutron instrument is as much a geochemical tool as is the chemical analysis of soil and stream sediment samples.

It is perhaps early to comment in detail on the possible scope of these methods which are still in their infancy. However, in general terms, it seems probable that the field gamma-neutron instrument is better suited to prospect appraisal, i.e. discrimination of barren and mineralized deposits, location of metal concentrations in known deposits and the tracing of their extensions. In prospecting virgin country, either method may be preferable as a means of locating concealed deposits, depending on the size and tenor of the soil anomalies developed. When there is an adequate drainage pattern, however, it is possible that stream sediment sampling could be used to good purpose as a primary reconnaissance method to delimit focal points for more detailed prospecting. Preliminary experiments have been undertaken which indicate that the field gamma-neutron instrument may also have an application in reconnaissance (S.H.U. Bowie, pers. comm.). Subject to further investigation, it seems probable that the use of both methods may well depend on such factors as geographical situation, personnel, and the economics of the local exploration problem.

A number of problems remain to be solved. Outstanding amongst these is the application of chemical methods of analysis to soils and stream sediments in the vicinity of concentrations of Be minerals other than beryl. In this connection, a great deal of research remains to be done concerning the hydromorphic and biogenic dispersion of Be, which could also have a particular bearing on the difficult problem of prospecting for all types of Be deposits concealed beneath transported overburden.

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APPENDIX I (TECHNIQUES)

1. SAMPLE COLLECTION AND PREPARATION

Kraft paper envelopes with dimensions 10 x 5 in. (to hold up to 1 Kg) and 5 x 3 in. (to hold 50-100g) were used for the collection and storage of large and small samples, respectively. The Kraft envelopes do not disintegrate if wet samples are collected, and they permit air or oven drying without removal of the material from the packets.

A. Rocks and Minerals

Outcrop samples consisted of a composite sample of small chips of rock collected from various parts of the outcrop, within an area of 100 square feet or less.

Bedrock samples were collected from the bottom of profiles or from channels 2 feet or less in length along the bottom of a trench; each sample consisted of only one rock type.

Minerals were selected from rock samples by hand-picking after partially breaking down the rock structure.

Both rocks and minerals were pulverised to a grain-size less than 100 microns in a porcelain or agate pestle and mortar.

B. Soils

For detailed profile investigations pits were excavated to bedrock. After preparing a fresh face, channel samples were taken throughout the whole depth, each horizon being sampled individually, and each sample (1 Kg) representing a depth no greater than 12 in. Fragments of soil material larger than $\frac{1}{2}$ in. diameter were discarded. Samples were treated by the size-analysis procedures described later, in order to establish their mechanical composition and the pattern of Be distribution in the size-fractions.

Routine samples were collected from small pits, deep enough to permit a clean subsoil sample (50-100g.) to be obtained, usually at a depth of 12-18 in. A topsoil sample was collected also at each sampling point (3-9 in. in depth). Fragments coarser than $\frac{1}{4}$-$\frac{1}{2}$ in. diameter were removed by hand. After drying, if necessary, the material was lightly crushed in a pestle and mortar in order to destroy the soil aggregate, and separated into +190 and -190 micron fractions (+80 and -80 mesh) by sieving. The coarse fraction was pulverised in a pestle and mortar before analysis, whereas the fine material was used without further preparation.

C. Vegetation

Leaves and twigs (2nd or 3rd year growth) were collected from trees of the selected species. The materials were sun-dried without removing them from the sample packets. In the laboratory twigs were reduced to shavings, and all samples were ashed at 500°C. in a furnace. The ash was treated in the same manner as a soil for the Be determination.

D. Stream Sediment

Stream sediment samples were scooped from the centre of the channel with an enamel cup (stream dry or flowing). An average sediment sample consisted of material up to $\frac{1}{4}$ in. diameter; clay and silt fractions were usually scarce.

For detailed size-analysis, samples were separated into fractions by the sedimentation procedure described below. Routine samples were sieved into +190 and -190 micron fractions, and the coarse fraction crushed before analysis.

Bank soils were collected on either side of the stream at the sediment sampling points. Both topsoil and soil at waterlevel were sampled if greater than 12 in. apart. This material was treated in the same manner as routine soil samples.

E. Waters

Water samples were collected in clean 500 ml or 1000 ml polythene bottles and acidified with 1 ml of 1:1 HNO_3 to prevent absorption of metal ions on the container walls. In the laboratory a sample was evaporated in 1000 ml beakers over a waterbath. When the volume had been reduced to 20 ml the liquid was transferred to a 25 ml silica crucible and the evaporation continued to dryness. The residue was then heated gently over a burner in order to remove traces of acid. The Be determination was carried out on the residue, as described for a soil sample, in the same crucible.

F. Size-Analysis Procedures

The patterns of Be distribution throughout the various size-fractions of soils and stream sediments were obtained by analysing the size fractions of samples which were separated either by dry-sieving or by sedimentation.

1. Dry-sieving

After breaking down the soil structure in a pestle and mortar, the samples were shaken in a nest of sieves with stainless-steel screens. The relationships between screen mesh and aperture-size are given in Table 46.

TABLE 46

Relation between screen-mesh and aperture-size of sieves

Type of screen	Mesh	Aperture-size (microns)	
		Nominal	Approximate
Silk	80	195	190
Stainless Steel	(¼ in.)	6,350	6,300
	10 Commercial	1,980	2,000
	20 do	894	900
	36 do.	471	470
	80 do.	186	190
	150 B.S.S.	104	100
	200 do.	76	80

In the following text, and in the body of the thesis, all references to size-fractions are in terms of approximate screen aperture-sizes in microns.

2. Sedimentation

It is impossible to obtain the complete breakdown of the soil aggregate with light crushing; this can only be achieved by wet-dispersal of the soil in the presence of an agent capable of separating all the clay aggregates into individual particles. In the present method the dispersing agent is sodium hexametaphosphate.

The fine material is separated into the following size-fractions:

Fine sand	20-80	micons	diameter
Silt	2-20	"	"
Clay	0-2	"	"

Procedure

The procedure is similar to that described by Piper (1950). A suitable amount (50-100g) of soil or sediment (-2000 micron material) is placed in a dispersing machine, 150 ml of a 1 per cent solution of sodium hexametaphosphate (suggested by Tooms, 1955) are added, and the mixture stirred very briskly for 5 minutes. It is then transferred to a 1 litre cylinder and the volume made up to 1 litre with demineralised water.

A uniform suspension is obtained by shaking end-over-end for 15 sec and the settling-time commences when the cylinder is returned to the bench. The amount of silt + clay in the sample is determined with the aid of a Bouyoucous hydrometer (calibrated in grams of suspended material per litre) after the suspension has settled for 5 min, and the amount of clay by taking a reading after 5 hours. The difference between the values is the amount of silt in the sample. If the temperature differs markedly from 19-20°C a correction must be made to the readings; 0.3 units should be added for every degree above 19.4°C, or the same amount subtracted for every degree below this temperature.

To recover the silt + clay material, the mixture is reshaken and allowed to settle for a specified period, which depends upon the amount of the suspension to be decanted from the cylinder and the temperature (Table 47 gives settling time if a depth of 10 cm. of suspension is decanted).

TABLE 47

Variation of settling time with temperature, before decantation of 10 cm of silt + clay and clay suspensions (after Piper, 1950)

Temperature (°C)	Silt + Clay		Clay	
	min	sec	hr	min
18	5	0	8	25
19	5	0	8	10
20	4	48	8	0
21	4	40	7	50
22	4	35	7	40
23	4	30	7	25
24	4	20	7	15
25	4	15	7	5

The first litre of silt + clay suspension decanted from the cylinder is collected in a beaker; the remainder is discarded and the decantation continued until no material remains in suspension after the specified settling time. The coarse fractions are removed from the cylinder, dried and sieved into fractions ranging from 20-2000 microns. All material coarser than 100 micron diameter is crushed to less than this size before analysis.

The 1 litre of silt + clay suspension is returned to the cylinder, shaken and allowed to settle for specified periods, which depend upon the depth of suspension to be decanted and the temperature (Table 47), before decantation of clay-size material. The first litre of clay suspension is collected and evaporated to dryness in a drying cupboard. The remaining clay material is removed by successive decantations until no material remains in suspension after the specified settling time. The silt fraction is then removed from the cylinder and dried. Both silt and clay fractions are crushed in a pestle and mortar, to break up aggregate, before analysis.

3. Comparison of dry-sieving and sedimentation

Two samples were treated by each of the two size-analysis procedures, in order to determine the effect of wet-dispersal in breaking down soil aggregates and in dislodging the fine material which adheres to the coarse fractions (Table 48).

TABLE 48

Comparison of mechanical composition and Be distribution pattern in size-fractions of soil samples treated by dry-sieving and sedimentation

Sample No.	Size-fraction (microns)	Dry-sieving		Sedimentation	
		weight %	p.p.m. Be	weight %	p.p.m. Be
201877-8-9 (soil over schist at Bepe 2)	900-2000	12.9	20	3.3	40
	470-900	23.6	13	3.0	54
	190-470	23.4	10	3.9	50
	100-190	13.7	7	9.8	25
	80-100	5.6	6	5.5	14
	20-80	21.8	5	21.9)	7)
	2-20			19.2) 74.5	6) 6
	0-2			33.4)	5)
202221 (soil over pegmatite at Mistress)	900-2000	15.6	130	11.0	200
	470-900	11.7	120	9.2	125
	190-470	29.3	110	16.2	100
	100-190	19.8	70	15.1	60
	80-100	11.0	75	6.3	45
	20-80	12.6	65	17.8)	48)
	2-20			12.9) 42.2	60) 40
	0-2			11.5)	5)

The comparisons indicate that considerable amounts of fine material may be included in the coarse fractions, particularly in soils derived from schist, if the samples are not treated by wet-dispersion. Consequently, the low Be content of the clay-size fraction (and other fine fractions of schist soil) may reduce markedly the correct Be values of coarse fractions of dry-sieved samples.

The small amounts of the fine fractions which are present in the stream sediments would, in general, have little effect on the Be values of the coarse fractions of dry-sieved samples.

2. ANALYTICAL PROCEDURES

A. Provisional Improved Buffer Method for Be Estimation

Procedure

1. Weigh 0.5g of sieved (or crushed) sample into a silica crucible (25 ml) containing 2g ammonium fluoride.
2. Mix and heat moderately for 5 min.
3. Break up residue with a spatula and continue heating strongly until fuming ceases.
4. When cool, add 5 ml of 0.2N HNO_3 and heat to boiling.
5. Add another 5 ml of 0.2N HNO_3, mix by stirring and allow the residue to settle (about 1 hour is required).
6. Transfer a 2 ml aliquot to a test tube (18 x 180 mm, previously calibrated at 10 and 12 ml) containing 10 ml of buffer solution.
7. Add 1 ml of 0.02 per cent berillon solution, invert to mix, and allow to stand 5 min.
8. Compare with standards.

9. If greater than the top standard, repeat with a smaller aliquot, diluting to 12 ml with 0.2N HNO_3 at step 6.

$$\text{Be in p.p.m.} = \frac{\text{20 x mcg Be in matching standard}}{\text{aliquot in ml}}$$

Standards: To 12 test tubes, each containing 10 ml of buffer solution, add respectively 0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 mcg of Be. Dilute to the 12 ml level with 0.2N HNO_3 and add 1 ml of 0.02 per cent berillon. Invert to mix and allow to stand for 5 min before use.

Reagents:

1. Ammonium fluoride.

2. 0.2 HNO_3: dilute 13 ml of acid (sp.gr. 1.42) to 1 litre with demineralised water.

3. Buffer solution: dissolve 95g of tri-sodium orthophosphate, 12g of ethylenediamine tetra-acetic acid (di-sodium salt), and 15 ml of N,N-di-(2-hydroxy-ethyl)-glycine (sodium salt, 33 per cent solution) in water and dilute to 1 litre.

This solution may not have the correct pH of 12.0, due to variations in pH of the tri-sodium phosphate solution which may vary by as much as 0.25 pH unit between batches of the reagent purchased from different suppliers. The adjustment to pH 12.0 is made by adding NaOH, and although it may be controlled with a pH meter it is preferable to proceed as follows, particularly under field conditions:

(i) Prepare 100 ml of 2 per cent NaOH solution.

(ii) To 10 test tubes containing 10 ml of buffer solution add 2 mcg Be and make up to 12 ml level with 0.2N HNO_3.

(iii) Add respectively 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 ml of 2 per cent NaOH to the tubes.

(iv) Add 1 ml of 0.02 per cent berillon solution to each tube, invert to mix, and inspect after 5 min. The tube in which the maximum blue colour has developed has correct pH. If several solutions have equal amounts of blue, choose the one in the centre.

(v) Add the corresponding amount of 2 per cent NaOH to the remaining 900 ml of buffer (i.e. 90 times the amount used to produce the maximum blue colour).

4. <u>0.002 per cent berillon solution</u>: dissolve 20 mg of berillon II in 100 ml of water.

5. <u>Standard Be solution</u> (2.5 mcg per ml): dissolve 196.4 mg of $BeSO_4.4H_2O$ in 100 ml of 0.2N HNO_3. Dilute 2.5 ml of this solution to 100 ml with 0.2N HNO_3.

B. Determination of Exchangeable-Be

The exchangeable-Be of clay samples was determined on an aliquot of the filtrate prepared for the estimation of base-exchange capacity (see below). The aliquot (50 ml or less) was evaporated to dryness in a 25 ml silica crucible over a waterbath, and the Be content of the dried residue was estimated by the buffer method described previously.

C. Determination of Readily-Soluble Be

One gram of clay sample was shaken for 1 min in a test tube with 10 ml of cold 0.2N HNO_3. After filtering the residue was washed with 0.2N HNO_3, and the filtrate evaporated to dryness in a 25 ml silica crucible over a waterbath. The traces of HNO_3 were removed with stronger heat over a burner. The Be determination was carried out on the residue in the same crucible by the buffer method.

D. Determination of Base-Exchange Capacity

The base-exchange capacity of the clay-size fraction of soils and sediments was determined by the method devised by Mehlich (1942), and used by Govett (1958).

Procedure

1. Leaching procedure

Place a known weight of soil (5-20g) in a filter funnel with paper and cover the soil with another filter paper. Place the funnel over a 100 ml volumetric flask. Leach the soil with 50 ml of solution A (or A'), which should be added drop by drop from a burette. After the solution has passed through the soil allow about 1 hour for drainage. Now leach with water to remove excess Ba, using just sufficient to bring the total volume of leachate + washings to 100 ml. Aliquots of the final leachate are used for the determination.

2. Estimation

Pipette 10 ml (if solution A used) or 20 ml (if solution A' used) of the soil extract into a 250 ml conical flask, add 5 ml of solution C and 2 drops of methyl orange. Titrate with solution D until the indicator has changed from orange to yellow. Add 2 drops of N-triethanolamine, 10 ml of solution B, and about 20 ml of alcohol. Mix thoroughly and then add about 300 mg of tetrahydroxyquinone. Continue to titrate with solution D, shaking vigorously after each small addition until the colour changes from yellow to rose-red. The end-point may be difficult to see due to the colour being masked by the yellow produced by methyl orange. The titre measures the base-exchange capacity which is expressed as m.e.q./100g of soil as in the formula:

$$\text{Base-exchange capacity} = \frac{500 \times (\text{ml of solution D})}{\text{aliquot (ml)} \times \text{sample weight (g)}}$$

3. Reagents

(i) Solution A: Barium chloride triethanolamine solution in water, approximately 0.2N with respect to Ba ions, and 0.12N with respect of OH ions.

Preparation:. **Dilute 50 ml of triethanolamine with** 1800 ml of distilled water. Add 130 ml of 1N-HCl to adjust to pH 8.2, then 49g $BaCl_2$. Stopper securely to protect from CO_2 of the air. Solution A need not be accurate to a prescribed normality, but it is essential to know its concentration and to prepare a

K_2SO_4 solution (solution B) having half the normality of a solution A (in terms of Ba ions), and a HCl solution (solution C) having a titration value equal to solution A.

(ii) Solution A': Dilute part of solution A with an equal volume of water. This is used for soils which have a low base-exchange capacity.

(iii) Solution B: Dissolve 17.5g dried K_2SO_4 in 2 litres of water. Pipette 10 ml into a flask, add 10 ml water, about 20 ml ethyl alcohol and mix thoroughly. Titrate this solution with solution A'. After the addition of about 8 ml of A', add 300 mg of tetrahydroxyquinone. The concentration of solution B is correct when the last drop of a 10 ml aliquot of A' produces a permanent rose-red colour.

(iv) Solution C: Prepare an approximately 0.12N solution of HCl. Pipette 10 ml into a flask, add 2 drops of methyl orange and titrate with solution A until the colour changes from orange to yellow. The concentration of solution C is correct when the last drop of a 10 ml aliquot of A turns the solution yellow.

(v) Solution D: A 0.05N barium chloride-triethanolamine solution is used to determine the actual amount of Ba absorbed by the soil. Weigh out 10.414g dried $BaCl_2$

and dissolve in 1 litre of water. Dilute 25 ml of triethanolamine in 900 ml of water, add about 65 ml of N HCl and adjust pH to approximately 8.2 . Dilute with water until 0.1N as determined by titration against a known volume of a known concentration of HCl, using methyl-orange as an indicator. Solution D is prepared by mixing equal volumes of the $BaCl_2$ and triethanolamine solutions. Atmospheric CO_2 does not interfere with the titrations.

APPENDIX II (PUBLICATIONS)

Publications in pocket of back cover:

A. DEBNAM, A. H., and WEBB, J. S., 1960.
Some geochemical anomalies in soil and stream sediment related to beryl pegmatites in Rhodesia and Uganda.
Trans. Instn Min. Metall., Lond., 69, 1959-60
(Bull. Instn Min. Metall., Lond., No. 641, April 1960)
329-344.

B. Discussion and Contributions for A.
Trans. Instn Min. Metall., Lond., 69, 1959-60
(Bull. Instn Min. Metall., Lond., No. 645, August 1960)
637-660.

Some Geochemical Anomalies in Soil and Stream Sediment Related to Beryl Pegmatites in Rhodesia and Uganda

A. H. DEBNAM, B.Sc, A.R.A.C.I., and
J. S. WEBB, A.R.S.M., B.Sc., Ph.D., D.I.C., MEMBER

Electronic Instruments for Detecting and Assaying Beryllium Ores

S. H. U. BOWIE, B.Sc., MEMBER, H. BISBY, B.Sc., A.M.I.E.E.,
K. C. BURKE, B.Sc., Ph.D., and F. H. HALE, A.M.Brit.I.R.E.

Field Determination of Beryllium in Soils for Geochemical Prospecting

E. C. HUNT, B.Sc., R. E. STANTON, D.I.C., and
R. A. WELLS, B.Sc., F.R.I.C., MEMBER

Report of joint discussion at June, 1960, General Meeting (Chairman: Professor David Williams, President). Papers published in April, 1960, pp. 329-69

The President, opening the meeting, said that it was an extraordinary one in more ways than one, for it was not the custom of the Institution to hold meetings so near Midsummer Day nor was it usual to discuss a single topic, in this case the search for beryllium ores, in three separate but closely related papers. He proposed that they should be presented *seriatim* and subsequently discussed *en bloc.*

Mr. A. H. Debnam, introducing his paper with Dr. Webb, said that it presented only provisional results of field work. More detailed laboratory studies were now available, for instance, the distribution of beryllium throughout different size fractions of soils and sediments, which might have a bearing on prospecting techniques and also supply information on the mode of occurrence of the beryllium.

Soil and sediment material coarser than 1980-μ diameter (+10 mesh) was discarded owing to the tedious crushing required and the large amount of sample necessary to provide representative results. The efficiency of the chemical attack fell off rapidly with increasing grain size, and the following results referred to crushed material except in the case of fractions

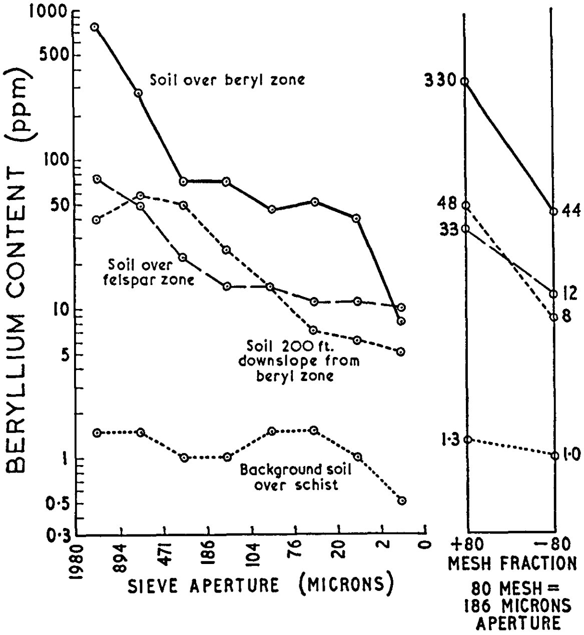

Fig. A.—Distribution of beryllium in size fractions of soils, Bepe 2 Claim, Southern Rhodesia.

less than 76 μ (—200 mesh) which showed no detectable difference in Be content before and after grinding.

At Bepe 2 the size distribution data showed (Fig. A):

(1) Irrespective of the position of an anomalous soil with regard to mineralization the beryllium content progressively decreased with particle size.

(2) The contrast between anomalous and background values for the +80 mesh fraction was between two and six times that for the —80 mesh fraction.

A very different picture was presented by the data for Ishasha (Fig. B):

(1) There was a bimodal distribution of beryllium in soil and colluvium, with concentrations in both the coarser fractions and the silt plus fine sand fraction (2–76 μ). That type of distribution persisted in the stream sediment near the dyke, but 3000 ft downstream the anomalous values in the coarse material were no longer evident.

(2) Analysis of the —80 mesh fraction invariably produced higher beryllium values than that of the +80 mesh fraction.

(3) Conclusions concerning contrast in sediment samples were difficult to draw, as the distribution of values in the background sediment

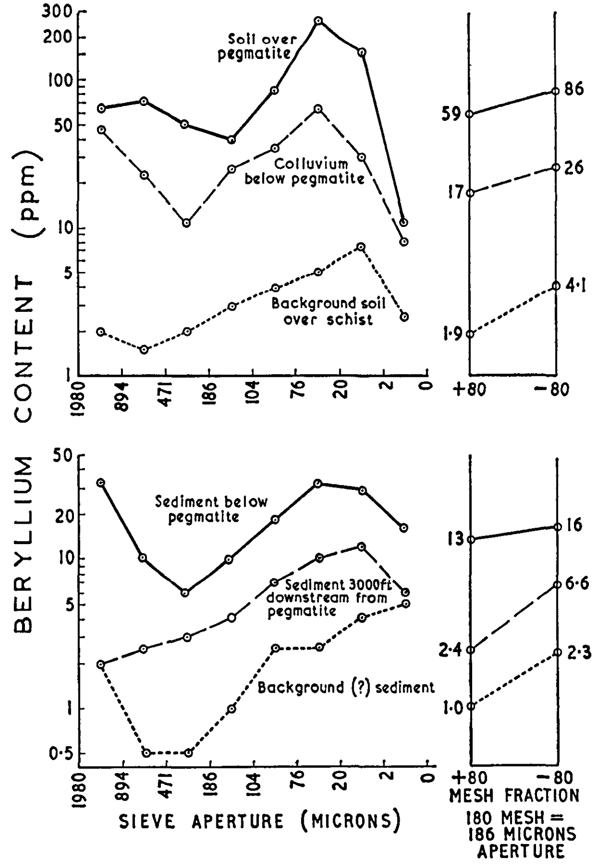

Fig. B.—Distribution of beryllium in size fractions of soils and sediments, Ishasha Claims, Uganda.

indicated that that particular sample might not in fact be a true background sample. On the available data, however, there was little difference in contrast between the +80 mesh and −80 mesh fractions, for both soil and sediment.

The effect of taking combined size fractions was illustrated in Fig. C. The data showed that major variations in the beryllium content of separate size fractions were largely eliminated when fractions greater than a given mesh size were composited; a similar effect was also observed when fractions finer than a given mesh size were combined, but in that case the low metal content of the clay fraction was emphasized.

The results demonstrated the importance of determining the distribution

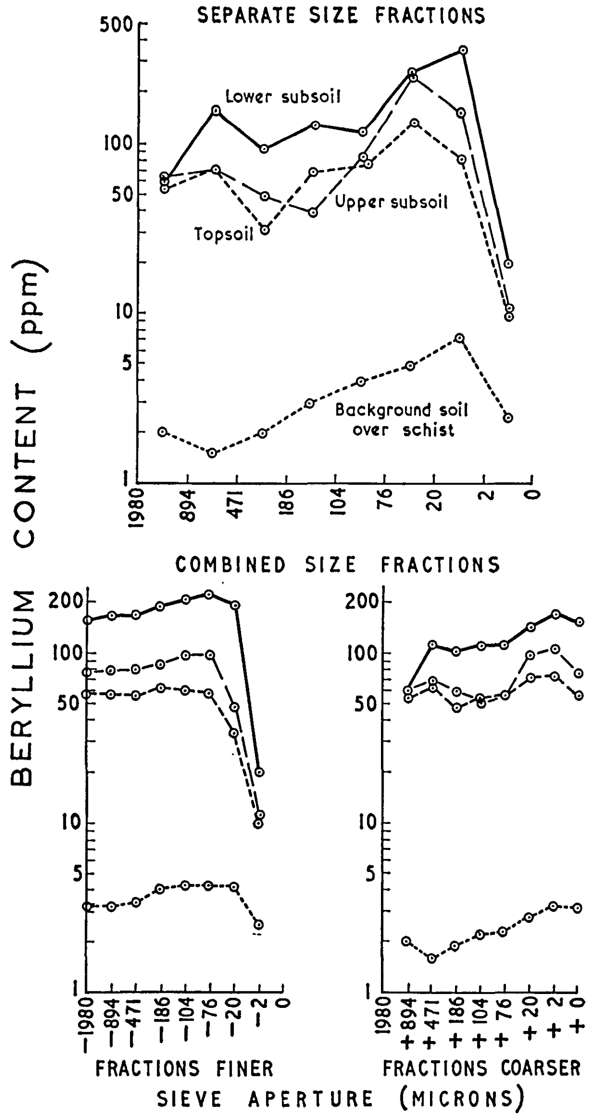

Fig. C.—Distribution of beryllium in size fractions of soils over pegmatite, Ishasha Claims Uganda.

of beryllium in the different size fractions when establishing a prospecting technique in any particular area. Thus at Bepe 2 the coarser fractions gave stronger soil anomalies than the finer fractions. At Ishasha, on the other hand, there was little difference between the contrast for the +80 mesh and the —80 mesh material. However, contrast in the coarser fractions was greatly reduced if the sample was not crushed, and for that reason it would be preferable in prospecting in that area to use the —80 mesh fraction. It had yet to be determined to what extent those results were generally applicable to other dykes in the two areas considered.

Reference was made in the paper to the beryllium content of pegmatite minerals as given by Beus. Very much lower values had been found in equivalent minerals from the pegmatites studied:

Be Content of Pegmatite Minerals (ppm)

Area	*Quartz*	*Felspar*	*Mica*
Bepe 2	1	2	15
Mistress	0·5	1	8
Ishasha	0·25	7·5	19

In conclusion the authors would like to emphasize the obvious fact that whether the beryllium anomalies were sought by field beryllium monitor readings or by the collection and analysis of geochemical samples, each approach was dependent on the natural development of beryllium dispersion patterns and as such both belonged to geochemical prospecting; the only fundamental differences were strictly those of analytical technique.

Mr. S. H. U. Bowie, introducing the second paper, said he proposed to devote the time available to demonstrating how the instruments were used, adding some information not available at the time the paper was submitted. Fig. 2 (p. 348) showed an antimony-124 source with the sample in an annular container around it. The source produced neutrons from any beryllium present in the sample and they were moderated by paraffin wax and measured by a ring of five BF_3 counters. The count rate was directly proportional to the beryllium content for any given weight of dry sample; thus any unknown could be assayed against a standard, the method being quick, accurate and non-destructive. Interferences due to naturally-occurring amounts of elements with a high neutron-capture cross-section were negligible and with a 100-mc antimony-124 source a sensitivity of the order of 2 ppm BeO could be obtained. The laboratory instrument had also been transistorized and in that form it could be used in a field camp or in a Land Rover to give assays of the same accuracy as could be obtained in the laboratory. [Mr. F. H. Hale then demonstrated how the instrument worked.]

The field equipment was a little more complex as it had to be made portable. Fig. 3 (p. 352) showed the gamma source positioned to give maximum irradiation of the ground while both counters and operators were shielded by a semi-circular section of lead. The sensitivity of the instrument with a 100-mc source was from 5–10 ppm BeO for a counting time of 10 minutes.

For *in situ* sampling high accuracy was unnecessary and for a grade of material currently classable as ore, i.e. upwards of 0·04 per cent BeO, little could be gained by prolonging the counting time beyond half a minute. Thus traverses could be made across a pegmatite body and an indication of the grade obtained very quickly. In correlating meter readings with grade the nature of the surface on which the instrument was placed was important as the conversion factor varied from about 24 for a plain surface to 15 for a surface with a relief of 1 to 2 in.

One of the main advantages of the instrument was that it gave an on-the-spot indication of BeO content, which enabled a preliminary examination to be broadened at will without the necessity of returning to base camp to undertake assays. That applied in reconnaissance work as well as in the assessment of known deposits. [A series of slides illustrating the instrument in use in Africa was shown.] A second important advantage of the instrument was that it measured total beryllium and that accounted for the (γ,n) values being 5 to 40 times higher over the same terrain as the colorimetric values given by Mr. Debnam and Dr. Webb. The results were similar for stream sediments, where Be ranges from 10 to 48 ppm were obtained with the beryllium monitor as compared with 2·5 to 7·5 by the colorimetric technique.

The average igneous rock contained about 10 ppm BeO and granites twice that amount. Even in sediments the content was 4 to 5 ppm, so that the field instrument had adequate sensitivity in its present form to detect any beryllium anomaly. A much smaller instrument would be particularly useful for mine control purposes where great sensitivity was not necessary.

The radiation hazard had proved to be much less when the instrument was in normal use than was the case when it was field-tested in Rhodesia. No operator had received any dose measurable on the film badges carried and nothing like the 0·4 rad referred to in the paper had since been recorded. It was clear, therefore, that although the instrument had to be treated with respect, it was perfectly safe to handle.

Mr. E. C. Hunt, presenting the third paper, said that, as part of the programme of the Beryllium Section of the Extraction of Metals Group of the National Chemical Laboratory, a rapid analytical method for beryllium suitable for use in the field for prospecting purposes had been developed. In it the Group had worked in close collaboration with Dr. Webb and his colleagues at Imperial College.

The problem of analysing soils for beryllium resolved itself into three parts: first, a method was required for rapidly breaking down refractory beryl; secondly, either the beryllium extracted from the soil had to be purified or the other elements had to be sequestered; and, thirdly, a colour-forming reagent, selective for beryllium, was required. The third part was largely solved by the Russians Lukin and Zavarikhina, who had carried out careful appraisals of chemical groups selective for beryllium and were able to synthesize a selective reagent for beryllium known as berillon II or just berillon, which gave colours varying from magenta to pure blue. The breakdown was effected quite simply by heating the soil with ammonium fluoride and interference from other ions was inhibited by the use of EDTA and dihydroxyethyl glycine.

The method was fairly rapid; he had conservatively estimated that 30 to 50 samples per man per day could be analysed. The method was sensitive; 0·05 μg of beryllium could be detected which, with the 10 times factor involved, gave a lower limit of 0·5 ppm beryllium.

The accuracy of the method could best be judged from the results given in the paper. The standard samples were used only after being analysed by two independent methods, the gamma-neutron assay being one of the methods in each case. The method was not tested on soils containing beryllium in forms other than beryl because no samples were available, but there was no reason why it should not be applied to other mineral types. Most beryllium minerals contained silica which was readily attacked by fluoride and volatilized as silicon tetrafluoride, thus breaking open the crystal lattice and enabling attack on the beryllium to take place.

The fluoride attack had proved to be very selective; the only metal found to be leached from the soil residue other than the alkali metals had been aluminium. Several metals interfered with the beryllium colour when in solution; those thought most likely to create difficulties were Al, Cu, Cr, Fe, Ti and V, either because of the sensitivity of their reaction for berillon (Cu, Cr, V) or because of their generally abundant occurrence in soils (Al, Fe, Ti). Those elements were specifically tested for by adding them, together with beryllium, to soils prior to analysis. In no instance was there any significant interference.

The sensitivity of the method could be increased by up to 100 per cent by using a lower pH value for the colour development. Blank and beryllium-bearing solutions gave similar magenta colours with berillon when acid, but with the addition of caustic soda the colours remained the same until a critical pH was reached at about 11 when the beryllium colour changed to blue. On further addition of caustic soda it tended to revert towards magenta. They had chosen to work with the more alkaline value of pH rather than the critical one in order to provide a safety margin and because of the increased stability of the colour. The solutions absorbed carbon dioxide from the atmosphere, which reduced their alkalinity, causing, at first, an apparent increase in beryllium content and then a complete loss of beryllium colour as the pH dropped below the critical value. They had always left their coloured solutions in open test tubes and found them to remain quite stable during one working day; when examined next day, however, there was an apparent increase of 10 to 25 per cent in beryllium content and after two weeks all standards had reverted to the blank colour. The practice was to prepare fresh standards each day.

The cost of the reagents used was about ¾d. per estimation, a bigger item being the cost of crucibles, which were attacked by ammonium fluoride. A life of 10 fusions added about 6d. to the cost of an estimation.

They had themselves prepared all the berillon used according to the method of Lukin and Zavarikhina, although it was now available commercially. The commercial material was somewhat inferior to their own.

Mr. C. B. Campbell said that the hitherto obscure position occupied by beryllium in papers read before the Institution, or similar bodies, on prospecting techniques and mining was, of course, explained by the fact that its ores, like mica, had been found and won by simple traditional methods of general applicability and that sector of the mining industry had been almost exclusively in the hands of smallworkers. Furthermore, interest in beryllium had developed significantly only over the last decade and during that time barely 100 000 tons of the ore mineral, beryl, had been mined from deposits scattered all over the world, mostly outside Western Europe. There had been scarcely any big names in beryl production and the methods of search for the ore and of working the deposits had almost invariably been on a scale which called for small capital outlay, no geological staffs, and hence no professional approach to exploration and development of reserves. The relatively small production of beryl had, in many areas, depended for its continuation on constant replenishment of easily-won sources, on a 'hand to mouth' basis. However, there were indications that such sources were finite and, if some of the developments and uses foreshadowed for beryllium (and mentioned at the beginning of Mr. Bowie's paper) came to pass, then economic conditions based on supply and demand would inevitably bring in more efficient methods, ore deposits of lower grade, or even new kinds of ore deposits and a new type of operator. Perhaps the days of the native prospector, with his sharp eyes, were numbered.

It was to anticipate the need for new prospecting tools which might arise from possibly large competing demands for source materials that the United Kingdom Atomic Energy Authority supported the research in the inter-related fields of geochemical prospecting and electronics, as applied to prospecting for beryllium and described in the papers. Although further development and testing of the chemical and radiometric methods had yet to be done, a phase had already been reached when some comparisons could be made and some provisional conclusions drawn by the potential user. The fact that tests had been conducted over identical ground in Southern Rhodesia enhanced the validity of the comparisons shown in the paper by Mr. Debnam and Dr. Webb. A feature which was at once apparent, however, was that the figures illustrating the soil anomalies were plotted to different scales, whereby the peaks derived radiometrically were reduced by a factor of five or six, with respect to the peaks obtained by chemical analysis of the -80-mesh soil fraction. Although that disparity in performance was admitted in the text, the authors had not given any clear indication from actual tests of the ability of the field beryllium monitor to detect anomalous values near the threshold of significance, apart from merely stating the respective limiting sensitivities of the titration and buffer techniques and that of the radiometric instrument. Even if analytical results were not subject to the fluctuations that occurred with corresponding radiometric readings, caused by random fragments of coarse beryl, the discernment of a significant dispersion pattern in primary reconnaissance might be inhibited if the extraction did not give a measure of the total beryllium content of the soil at the sampling point. It was in that respect that the radiometric method appeared to score, provided that sufficient readings were taken, and there was the further advantage that they could be interpreted and followed up as the traverse proceeded, without pause for analytical determinations.

He would agree therefore with the general conclusion that the field beryllium monitor was better suited to all aspects of prospect appraisal, especially for those of pegmatitic type. As hand-picking methods were still used in mining beryl, it was the coarse beryl (i.e. $+\frac{3}{8}$- to $\frac{1}{2}$-in fragments) that was being sought in the eluvium and soils on the margins of pegmatites: the fines were left behind in the ground. The further application of the field monitor in actual mining, for outlining beryl-bearing zones or for grade control, also deserved emphasis. But if there were no prospects in sight (and the presence of pegmatitic deposits was usually recognizable where there was float to be seen), the prospector was more than ever in need of assistance. Mr. Debnam and Dr. Webb speculated in their conclusions that either method might be effective in prospecting virgin country, but, in fact, comparative tests had not yet been conducted, particularly in regard to suitable sampling intervals. That was because suitable large and undisturbed areas were very difficult to find in countries such as Southern Rhodesia where there had been a beryl boom. But in southwest Uganda prospecting for beryl had been much less thorough and there the drainage patterns and thick overburden and vegetation provided an opportunity for geochemical tools, either analytical or radiometric, to show their paces. In reading what had been achieved around the Ishasha Claims by chemical analytical techniques applied to stream sediment sampling, one gained a glimpse of what might be one of the few environments where topographic conditions might put radiometric methods at a disadvantage for primary reconnaissance, if only on grounds of portability. But the claim to the discovery of one new pegmatite in the course of that work might well be qualified by substituting 'unrecognized' for 'unsuspected', since that whole area abounded in float of a kind which might indicate the presence of a swarm of pegmatites and the prospector would be 'on his toes' in any case.

The statement by Mr. Bowie and his colleagues that the field (γ, n) instrument was considered to be as valuable in the search for beryllium as the Geiger-Müller or scintillation counter had been for uranium, was a fair analogy. In the case of beryllium the radiometric method had the advantage that it was specific for the metal being sought and factors such as disequilibrium did not require consideration. But there were limits to which the bulk, weight and cost of the field beryllium detector could be reduced and it was unlikely that the instrument would be distributed on the same scale as the Geiger counter was, even if prospecting activity for beryllium were ever to reach similar levels of effort and expenditure. The supply of sources to men working in the bush involved a certain amount of rear echelon support of which the lone uranium prospector had no need. The transporting of the antimony source in a vehicle also presented minor problems, such as reduction of passenger capacity and the need to mount a guard at stops. The loss of a source had to be prevented and the breakage of a source container had to be cleared up promptly with the resources available. Both those contingencies were, however, unlikely to occur if carefully-designed routines were strictly adhered to and understood by the prospecting party, but they were not the sort of accident risks which insurance companies would readily accept.

Among the valuable contributions which the field (γ, n) instruments had made in operational use by the U.K.A.E.A. in Southern Rhodesia and Uganda were not merely the saving of time and wages but in reducing the need to transport large parties of labourers to areas where the meagre population made local recruitment difficult. The number of vehicles for transport of food and water to the bush was thereby considerably reduced and carriage of large numbers of samples, amounting to several tons per week, had also been reduced to almost negligible proportions. Likewise, the routine use of one radiometric assay equipment in a base laboratory in Southern Rhodesia had obviated the need to provide either chemical analytical facilities or the expense and delay of sending samples to a distant firm of analysts.

Dr. P. A. Sabine* welcomed the three varied, and perhaps in part contradictory, papers. Although they described very different methods and their use, they did have one theme which had been recurrent in recent years, namely the necessity for advanced instrumentation in seeking low-grade deposits or ones with fugitive characteristics.

He sought amplification of the figures shown in Fig. 2 (p. 334) of the paper by Debnam and Webb, in which colorimetry and spectrography yielded about 70–80 ppm and field beryllium monitor about 2000 ppm. What was being compared? The speaker also asked Mr. Bowie and his co-authors what the rates of work were for those methods when compared on the basis of what could be measured or detected in the field.

Professor C. F. Davidson said that he had to declare a special interest in anything relating to beryl, since an old name for that mineral was davidsonite, given in 1836 in honour of a Scottish professor, James Davidson of Aberdeen. He regretted that the Greeks had a word for it before the Scots did!

For various reasons enumerated in the papers, geopoliticians were encouraging explorations for beryllium ores. The immense amount of research on beryllium mineralogy and geochemistry currently being reported from the U.S.S.R. could not escape notice, nor could the many new analyses of beryllium minerals from China recently listed in Soviet literature. To enable the British territories to meet a much increased demand for the metal if it should arise, new prospecting techniques would have to be established so that new orebodies and in particular new kinds of orebody could be discovered. The papers under discussion were an important advance in that direction.

In considering the field analytical method developed by Messrs. Hunt, Stanton and Wells, they could not fail to be impressed by the skill with which chemists could conduct such complicated assays at a speed of 40 determinations per man-day. It would be noted, however, that while their technique was claimed to be 20 times more sensitive than the radiometric method, on Mr. Bowie's published figures it was only three times more sensitive, due allowance being made for differing forms of reporting (Be v. BeO). In any case both approaches were more than sensitive enough to cope with any foreseeable prospecting problems. That was also true of yet another mode of analysis for beryllium in rocks and soils

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*Chief Petrographer, Geological Survey and Museum, London.

recently reported from the U.S.S.R.,[1] which was based on the fluorescence of beryllium complexes with morin. It seemed at first glance that the latest Russian procedure was more tedious than the earlier, berillon, technique, but it would be of interest to have the chemists' views.

Perhaps some comment might also be made on the hydrogeochemical prospecting method lately studied in the Soviet Union,[2] which was based on the spectrographic assay[3,4] of the dissolved solids in groundwaters. Out of 693 samples investigated, all save 17 had only 0·000n per cent beryllium in the total solids; but the anomalous 17 waters, with Be = 0·0n – 0·00n per cent, all derived from beryl-bearing wolframite-molybdenite deposits. Maybe such water-sampling techniques could be improved upon by use of berillon. For higher-grade material an electronic mode of analysis involving alpha bombardment had recently been worked out by Plaksin and others.[5]

The gamma-neutron instruments developed by Mr. Bowie and his associates, and the related equipment described in recent North American papers, would undoubtedly revolutionize prospecting and assaying. But when Mr. Bowie wrote that 'Experience has shown that it is possible to carry out assays on ore material with one instrument at a rate of 10 000 a year with semi-skilled labour' one wondered how far that was extrapolation. On a 40-hour week that total was equivalent to five 10-min assays each hour, with a minute or two extra for noting results and changing samples. He wondered if the equipment was so perfected that no time whatever had to be allowed for break-downs, and if the administrative arrangements were so geared that no delays occurred in shipping new sources of ^{124}Sb to the field several times a year. One wondered also whether semi-skilled labour would be eligible for an operator's licence. To control health hazards in North America the use of such equipment containing artificial radioactive sources was already illegal except where the operator was licensed; and similar licensing would doubtless become obligatory in Britain after the passage of the 1960 Bill concerned with the Control of Radioactive Substances. The recommendation that operators should carry quartz-fibre dosimeters did not mention where they should be worn; but, since in normal use of the prospecting equipment the radiation must be much greater near the ground, it would seem that the dosimeters should be carried not any higher than hip level. The recommended procedure with the Canadian berylometer was to wear a film badge at ankle height.

The results arrived at in the geochemical prospecting studies of Mr. Debnam and Dr. Webb were more encouraging than any yet reached in the U.S.S.R., where such techniques were apparently not much favoured. Indeed, in two recent Russian handbooks[6,7] for beryllium prospectors (30 000 copies had been issued!) there was no mention of geochemical methods at all. Apparently primary aureoles were not common around beryl pegmatites—in one documented case[8] where a pegmatite cut amphibolite, a detectable anomaly (only 5–10 ppm) in the basic country-rock was confined to 1–2 m from the dyke wall. But the authors' recognition

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[1] etc. see references at the end of this contribution.

that a secondary aureole or train of beryllium enrichment might persist for a considerable distance in soil, eluvium or alluvium was a big step forward. However, one important query arose in connexion with their determinations of the local background values, recorded at 1–2 ppm. These were consistently lower than one had reason to expect, consistently lower, for example, than the clarke of beryllium in the earth's crust, recently calculated by Beus[9] to be 3·5 ppm. They were very much lower than the beryllium content of most granites, which in 636 determinations of rocks from the Soviet Union and China ranged from 1 to 25 ppm, with a weighted average at 5 ppm.[9] They were lower than the content in most analysed bauxites and laterites,[10] which (except in limestone country) carried if anything a shade more beryllium than the underlying country-rock. Accepting the background assays it seemed reasonable to ask where the missing beryllium ended up.

There would be general agreement that the best way of augmenting the output of beryllium ores was to undertake much more research into the geochemistry and extraction metallurgy of the element. In that connexion it was of interest that an extensive study of beryllium geochemistry had just been published by the U.S.S.R. Academy of Sciences.[11] Perhaps in years to come large-tonnage low-grade sources such as greisens and helvite skarns would become exploitable; and since beryllium-enriched idocrase was as diagnostic of beryllium provinces as tin-bearing biotite was of stanniferous granite, a useful prospecting method might be to make electronic assays of heavy concentrates from stream beds. There were tens of thousands of little packets of those concentrates in the collections of the Overseas Geological Surveys. If the portable gamma-neutron equipment were of sufficient sensitivity to make quick assays of those small samples, such an examination might yield interesting results.

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Dr. J. S. Webb said he wished to make quite clear his and Mr. Debnam's viewpoint regarding the different methods of determining beryllium dispersion patterns. At the request of the U.K. Atomic Energy Authority, they had undertaken to investigate the possibility of using geochemical sampling techniques as part of the Authority's general investigation of prospecting for beryllium. They held no special brief for any particular method of determining the Be content of soil, rock or stream sediment. The fact that their paper was primarily concerned with the results obtained by chemical analysis of geochemical samples arose from the nature of the work they had been asked to do and did not mean that they necessarily preferred that approach, or indeed chemical analysis, to using the beryllium monitor.

It should be stressed that their paper was based on the preliminary data obtained during the course of an initial pilot study and the subsequent field sampling phase of their work. The analytical method employed was the only field method available at that time. Even that method had not been devised when the pilot study was undertaken, for which it had been necessary to rely on the rather inadequate data given by simple semi-quantitative spectrography.

The beryllium monitor readings presented in the paper were kindly provided by Mr. Bowie and Mr. Burke, with whom they had discussed comparison of the instrumental and chemical methods. The provisional conclusions given in the paper represented an impartial synthesis of those discussions; clearly the final scope and limitations of each method would not be determined until much more work had been done.

Of particular importance were (*a*) the applicability of the chemical method to forms of beryllium other than beryl and (*b*) the relative efficiency of the beryllium monitor in reconnaissance surveys, where it might be desirable to detect with adequate discrimination extremely low concentrations of Be. Another of the many aspects which remained to be explored was the possibility of using some other element as a pathfinder for beryllium, particularly those elements which were more mobile in the zone of weathering and might give more extensive dispersion patterns.

In reply to Professor Davidson's query concerning background values, it should be pointed out that their data referred solely to the −80-mesh fraction of soil and sediment derived from specific rocks and consequently could not be directly compared with average abundance figures. They were grateful to Professor Davidson for drawing their attention to the more recent Russian literature which had not yet come to their notice.

Mr. R. A. Wells agreed with Dr. Webb that if he were a prospector with sufficient resources looking for beryllium, he would use a portable electronic instrument.

The points raised about the disparity between chemical and gamma-neutron results in Dr. Webb's paper should be cleared up. When confronted with the same sample, both techniques gave the same answer; the apparent disparity arose out of the different sampling techniques used. The instrumental method gave an answer relating to a sample 1 sq. ft in area and 3 in. in depth. When used to assess a beryl-bearing pegmatite the results obtained would reflect the presence of relatively large heterogeneously-scattered crystals of beryl. That was illustrated by the erratic type curve in Fig. 4D of Dr. Webb's paper (p. 337). In the chemical method, analyses were carried out on the −80-mesh material sieved from each sample. Thus, any large crystals of beryl would be removed by the sampling technique and a relatively smooth anomaly curve would be obtained, as shown in Fig. 4C (p. 337). Results similar to the instrumental method would be obtained chemically if the determination were made either on the whole sample ground to −80-mesh, or if a portion of the unground sample were taken for analysis and the fusion technique modified so as to ensure breakdown of larger crystals. The instrumental method had the obvious advantage of giving an integrated answer for the beryllium content of a sample 0·3 cu. ft in volume.

It was not possible to give a clear-cut answer regarding relative sensitivity of the two methods. As stated in the paper by Mr. Bowie and his colleagues the instrumental method could detect 5 ppm, but that could be varied depending upon the size of gamma source and counting time the operator was prepared to use, and upon the prevailing background count and surface relief. The chemical method could readily detect 0·5 ppm and, by simple modification, 0·1 ppm. The method used for pH control in the chemical method given in the National Chemical Laboratory paper was based on keeping the technique as simple and as robust as possible. That that resulted in some loss of sensitivity was immaterial, since the resulting sensitivity was more than adequate.

The fluorimetric method using morin, to which reference had been made, was in continuous routine use at N.C.L. for the determination of beryllium in samples arising from air monitoring for health purposes. The method gave a performance at least the equal of the usual spectrographic method and no difficulty was experienced in determining beryllium down to 0·2 μg. The method was, however, definitely a laboratory technique, considerably more complex than the field method using berillon described in the paper. No effort had so far been made to apply any of the methods mentioned to the determination of beryllium in natural waters.

The question of determination of beryllium by alpha irradiation had been raised. While that might be possible, such a method had the disadvantage that it would not be specific for beryllium, and there were many more difficulties arising out of the use of alpha rather than gamma sources.

A figure of 10 000 samples a year had been mentioned in Mr. Bowie's paper. That referred to the number of assays it was possible to carry out on one instrument on ore grade material in the laboratory. It should be pointed out, however, that the counting time required for a sample was both a function of the accuracy required and the grade of the sample. In analysing samples by the gamma-neutron technique at N.C.L. a counting time of several hours per sample was often found to be necessary, particularly if a high order of accuracy was required, or if the sample was a tailing or middling sample from some beneficiation process.

Dr. K. F. G. Hosking said that the writers of the three papers were to be congratulated on developing ways and means of determining beryllium which were well-suited to the needs of those engaged in the prospection, mining and beneficiation of material containing the element.

He was, however, surprised to read in two of the papers statements to the effect that, with the possible exception of the Jedwab-modified quinalizarin test for beryl, no adequate and simple field-tests for beryllium-bearing minerals were known. There were, in point of fact, a number of good tests for beryllium and beryllium-bearing species, and some of them had been known for 20 or 30 years. Thus, the *p*-nitrobenzene-azo-orcinol test—which was developed by Komarowsky and Poluektoff in 1933*—was an excellent test for the element in question when it occurred as a major component in a mineral, and although a 25 per cent aqueous solution of potassium cyanide was used to complex interfering elements, it did not seriously militate against the employment of that excellent aid to the identification of beryllium-bearing species in the field.

One might also mention the test, developed by Zermatten in 1933,† for demonstrating the presence of beryllium in rocks and minerals. The test simply involved fusing a little of the finely-powdered sample with fusion mixture on a magnesia rod, then powdering the product in a depression on a black spot-plate and dissolving the powder in a few drops of dilute hydrochloric acid. One drop of a saturated solution of Morin in methanol was added and then a few drops of dilute sodium hydroxide. The presence of beryllium was indicated by the development of a yellow-green fluorescent solution. On adding dilute hydrochloric acid the colour either disappeared or changed to blue-green (indicating the presence of Sn, Zr or Al).

Members of the danalite-helvite-genthelvite series—species which might yet become important sources of beryllium—could be readily identified by Gruner's staining test.‡ A little of the crushed sample was boiled for a few minutes with arsenious oxide and dilute sulphuric acid, which caused members of the above series to be stained bright yellow.

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*KOMAROWSKY, A. S., and POLUEKTOFF, N. S. Über eine neue Tupfelreaktion des Berylliums. *Mikrochemie*, **14**, 1933, 315–7.

†ZERMATTEN, H. L. J. A reaction for beryllium in minerals and rocks. *Proc. Acad. Sci. Amst.*, **36**, no. 10, 1933, 899–900.

‡GLASS, J. J., JOHNS, R. H., and STEVENS, R. E. Helvite and danalite from New Mexico and the helvite group. *Amer. Min.*, **29**, 1944, 163–91.

A number of other good and simple aids to the identification of beryllium species had also been known for some years.

Although a diffusion column possessed certain obvious drawbacks as an analytical tool, it was, nevertheless, being used for detecting beryl in crushed pegmatite material, and the beryl band-width could, doubtless, be made the basis of semi-quantitative determinations. As a better alternative, the apparatus in which the column was developed could, without undue complication, be so modified that the mineral reporting in the beryl band could be isolated and then weighed.

The speaker thought that the method of Hunt, Stanton and Wells for detecting beryllium in soils, etc., was quite elegant, and he said that though the writers were careful to state that possibly ammonium fluoride might not attack beryllium-bearing minerals other than beryl, his own work indicated that many of the species in question succumbed to it. He was of the opinion, however, that chrysoberyl needed to be fused with pyrosulphate if it were to be decomposed. Certainly the extent to which ammonium fluoride attacked beryllium-bearing species must be fully investigated as one might well wish to investigate, say, skarns, in which any beryllium present was likely to occur as danalite or helvite. Furthermore, the mode of occurrence of beryllium in granites—some of which might become the low-grade/high-tonnage beryllium ores of the future—was still imperfectly known and clearly needed to be determined. Until that was done their economic potential could not be truly assessed, nor could the results of a geochemical survey carried out over them be fully interpreted.

Hunt and his co-workers had omitted to mention to what extent zinc interfered (see Table I, p. 365). That element should be investigated as sphalerite occurred with certain beryllium species (for example, with helvite in Cornwall), and, of course, helvite, danalite, and genthelvite contained some zinc.

He regarded it important that the writers of the geochemical papers should boldly state the precautions to be taken when preparing and using the stronger beryllium solutions as beryllium was a very toxic substance.

While in Southern Rhodesia last year he was privileged to see both the field beryllium detector and the large laboratory model in operation. Although the weight of the field instrument (40 lb) might be disconcerting to some, it was not really a serious drawback, and no difficulty was encountered because of its weight when he saw it used on the steep hillside where the helvite-bearing Casa Ventura pegmatite outcropped. In his opinion the field-model was of inestimable value for detecting and determining beryllium in outcropping rocks and in mines and quarries. Furthermore, although a pit had to be dug for the instrument if the beryllium content of all but the uppermost soil-horizon were to be determined, that did not detract from its value as a prospecting aid unless unusually deep horizons had to be investigated and labour was expensive. However, that the instrument could not be used to investigate water-covered stream sediments was a serious drawback which was not really offset by the fact that the larger laboratory model could, on occasion, be installed in a field-laboratory. Obviously, if large areas were to be investigated, sediment samples could be transported, say, by air, to a central, and possibly distant, laboratory where they could be examined by means of the large instrument. Even then, unless beryllium alone were being sought (and that was unlikely unless its monetary value were to increase greatly), it would probably be better to use spectrographic methods of analysis. Chiefly because the chemical methods could be employed *in the field* to determine the beryllium content of stream sediments, he thought them superior to the instrument method when one wished to carry out a regional reconnaissance.

Finally, the numerous recent discoveries of beryllium in Cornwall and Devon (particularly by Mr. Arthur Kingsbury of the Oxford University Museum) served to indicate that exploration by the means made available by the writers of the papers under discussion was likely to reveal that the world contained many more potentially useful deposits of the element than was commonly believed. Though there was no reason for thinking that the West Country would be a beryllium producer—certainly not in the foreseeable future—yet already it was clear that it was an ideal area for investigating the geochemistry of beryllium and for testing the various exploration methods: that the region was a unique natural laboratory was still not generally appreciated.

The manner of occurrence of the element in Cornwall and Devon paralleled that of the United States. Beryl, chrysoberyl, phenakite (rhombohedral habit), beryllonite, herderite, rhodizite and bertrandite occurred in some of the pegmatites. Prismatic phenakite, associated with cassiterite and sulphides, was found in certain quartz/felspar veins in the thermally and pneumatolytically altered slate near the granite. Danalite and helvite had been reported in and around veins in skarn-type rocks which had been derived from the alteration of greenstones and impure limestones near the granite masses. Euclase had been identified in cassiterite/wolframite greisen-bordered veins, and bertrandite in normal hypothermal tin-bearing lodes. Certain beryllium-bearing species were also known to occur in minor or trace amounts in some of the sediments of rivers draining the granite.

Mr. D. N. Moir, referring to the paper by Mr. Bowie and his colleagues, said he had recently seen an abstract of a paper by Aydarkin* in which an assaying instrument was described utilizing the (γ, n) reaction, but very few details were given. The accuracy of the instrument was poor and he wondered if the authors had seen the paper and could give further details, or comment on the apparatus.

He would like the authors' opinion on the minimum sample size which could be estimated in the assay equipment. At Warren Spring Laboratory they had successively reduced the sample size down from 70 to 30 and finally to 15 g and were quite satisfied with the results. That minimum sample size was of some importance from the mineral dresser's point of

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*AYDARKIN, B. S., *et al.* A method of determining beryllium in ores by photoneutrons. *Trudy Radievogo Inst. im V.G. Khlopina,* **7,** 1957, 89–93 (*Nuclear Sci. Abstr.,* **14,** 15 Jan. 1960, no. 202, 29).

view as small samples frequently arose from screen analyses or other test work which required rapid assay. He realized that they could always be diluted with some inert material such as quartz to increase the weight but that was not always desirable, as the fraction might be required intact at some subsequent stage.

There were several ways in which the assay equipment scored over the chemical method which were of particular interest to the mineral dresser. First, the sample did not have to be crushed through the 80-100 mesh, as was usually done with samples submitted for chemical analysis. That meant that provided a representative sample of the necessary size could be obtained from the main bulk of the product there was no need to crush at all. Furthermore, the sample was restored intact and could be used for further examination. That was particularly useful when the original product was of small weight. He would like to make it clear, however, that he was speaking of laboratory products of less than 30 mesh B.S.

Secondly, it often happened that a rapid assessment of a few test products could indicate a future line of attack and there the assay equipment was most useful. A short count lasting 5 min generally enabled a sufficiently accurate estimate of the assay to be made and the value of that particular test assessed in terms of, say, a pair of products. Subsequently, the sample might be estimated to the required degree of accuracy for metallurgical balance purposes.

Thirdly, the instrument was invaluable for the pilot-plant testing of beryllium ores where quick assessment was of great assistance in the control and tuning up of such a plant.

At Warren Spring Laboratory there were two assay units and it had been found convenient to have one carrying a 100-millicurie source which could be used for counting low-grade products, and the second unit carried a 50-millicurie source which was used for counting high-grade samples. The 50-millicurie source was in fact a half-decayed 100-millicurie source. As the strong source declined in strength its duty was changed and it was used for counting high-grade samples while the expended 50-millicurie source was replaced by a fresh 100-millicurie source and used for counting low-grade samples.

He would like to ask the authors what, if any, snags there would be in assaying BeO in solution as it seemed a logical step to take.

Coming to the portable prospecting instrument it seemed clear that, owing to the peaky nature of the curve shown in Fig. 8 (p. 354), the presence of a beryl crystal on the median line of the instrument would give a very different response to one lying on the edge of the base and thus a large number of samples would have to be taken to ensure good agreement between estimated and real assays. That seemed to work out in practice as shown in Table VI (p. 356).

Finally, the results achieved using that principle appeared to be so outstanding that they raised the question of the possibility of applying a similar principle to the assaying of any other elements which were difficult to assay by chemical means. He realized that that was not probably within the province of the U.K. Atomic Energy Authority but perhaps the authors might care to comment on the suggestion.

Mr. J. R. Stevens said that he would like to refer to the gamma-neutron equipment for determination of beryllium. They now had excellent equipment for beryllium exploration, but when workable beryl deposits were located the beryl needed to be extracted and handpicking would in time be replaced by other methods of beneficiation. Work on flotation of beryl was being done with some success, particularly on a laboratory scale, but he felt that progress in that field on a pilot or full plant scale was retarded by the lack of equipment which could continiously monitor the beryllium contents of products in the form of a pulp stream. The laboratory equipment appeared capable of modification to serve that purpose and perhaps the authors would give their views on the feasibility of producing such apparatus.

Dr. D. A. O. Morgan said that he had until recently been a member of the Atomic Energy Authority and concerned in the field work in East Africa. He felt it might be of interest to know that the problem originally set was to discover how much beryllium oxide there was in (*a*) eluvium and (*b*) solid rock, and thereafter to estimate costs of extraction and transportation to ocean port f.o.b. It was a very interesting problem and, as it came about before the advent of the field gamma-neutron beryllium detector, teams concerned had to tackle the then known beryl deposits in the traditional way.

In order to evolve a special technique for evaluation of beryllium deposits, one particular deposit in southwestern Uganda was selected for intensive investigation. Normal methods were employed and involved soil sampling for geochemical tests, pitting on a grid, and deep trenching followed by underground work. The team was fortunate in that there was already a small producing underground beryl mine on the property. In the absence of field gamma-neutron apparatus, however, the sporadic nature of beryl mineralization necessitated taking large samples at regular intervals. Channel sampling was adopted, each sample being approximately 100 lb in weight. Those were reduced in a specially-designed mobile field unit consisting of primary and secondary crushers, followed by a plate grinder. Pulps for assay weighed about 120 g. Fortunately, by the time pulps had begun to accumulate, the static gamma-neutron assay apparatus, designed and produced by the A.E.R.E., had been installed in the Authority's offices in Salisbury, Southern Rhodesia. Pulps were accordingly flown there and assay results were received most expeditiously.

He had worked with the field gamma-neutron detector for only a short time, but sufficient to satisfy him that its use would save much pitting and trenching in prospecting beryllium deposits. Moreover, it rendered unnecessary much of the channel sampling in trenches and pits. He was of the opinion, however, that in restricted spaces underground use of the apparatus was not to be recommended and that, in small underground openings, it was preferable to taking large channel samples.

Demand for the metal was at present small enough to be satisfied by production from small workings, but, if the world required larger tonnages in the future, it would be necessary, as had happened with copper and other base metals, for the price to rise. Besides the possible sources of low-grade ore suggested by Professor Davidson, pegmatites themselves—in certain conditions—could provide considerable tonnages of such grade. Indeed the particular prospect intensively investigated in Uganda was found to consist of a pegmatite swarm contained in soft, fine-grained granite. Given a sufficiently high price for beryllium oxide, the whole deposit could be worked opencast in a mechanized operation, pegmatite being sent to the mill and granite to waste.

Mr. C. B. Forgan said that quite clearly one of the basic things which had been brought out was the considerable advance in analytical techniques during recent years which not only aided the exploration phase necessary to find and evaluate the low-grade ores but also would find application in the practical control of concentration processes as yet not developed into commercial use. Comparatively recently while it was quite possible to obtain reasonable standards of accuracy in respect to material amounting to almost pure beryl (i.e. the hand-picked product assaying 10 to 14 per cent BeO) such was by no means the case when the determination of content was concerned with samples of crude ore, or partial products therefrom, at levels ranging, say, from 0·05 to 0·5 per cent BeO. It was to be noted that the papers dealt with still lower proportions, i.e. *c.* 10 ppm or in other words 0·001 per cent, variously stated in the papers in terms of either beryllium metal or BeO.

He felt it prudent to sound a note of caution in regard to the statement on p. 332, viz. 'beryl pegmatites of marginal or economic grade, i.e. *c.* 0·05 per cent BeO'. That expression in regard to material containing 0·05 per cent BeO might be interpreted as an indication of an acceptable grade for economic working relative to the currently ruling levels of mining and treatment costs and pricing of product. Neglecting mining dilution and treatment losses, that statement implied that at least 200 tons of crude ore needed to be mined and processed in order to yield 1 ton of beryl-bearing concentrate which, if of grade 10 per cent BeO, currently commanded a price at mine of about £100 per ton. Clearly the terminology used in the paper referring to an 'economic grade' required some qualification.

Expanded use of beryllium metal in industry, as with other newer specialist metals, required assurance of adequate supplies of the raw material, in that case beryl-bearing ore. Hitherto supplies of the product beryl had relied entirely on production emanating from selective mining combined with hand-picking relative to extremely shallow small-worker operations. Professor Davidson had advanced the view that discovery of a type of deposit containing a beryllium-bearing mineral different from beryl was required and he suggested that geochemical research could well be turned to methods of ensuring it. The speaker considered that there was a possibility of satisfying any immediately-foreseeable increased demand by the bulk mining of beryl-bearing pegmatite-type ores, given stimulation of price for the product in accord with the mining and somewhat complex treatment procedures required.

Mr. C. B. Campbell said that he would like to make a few remarks about economics in answer to Mr. Forgan. In discussing a grade such as

0·05 per cent BeO, it was also necessary to consider whether the material was soft or hard rock, at surface or underground. In Southern Rhodesia it had been found that a number of smallworkers had made profits in recent years out of beryl deposits where the overall grade was as low as 0·02 per cent. But it should be remembered that in the hand-picking of eluvium or weathered material at the surface, the mill man did not come into the picture: recoveries of beryl were nothing like 100 per cent but were more likely to be around 25 per cent. One of the features of the industry in its present state was that the 'eyes had been picked out' of most of the pegmatitic deposits that had been worked. Average grade alone therefore did not mean very much in assessing profitability where operators were able to rove in search of easily won material. The main criterion in the past had been the availability of easily removable large crystals of beryl at or near the surface.

He would like to amplify his earlier remarks about insurance and the loss of the source of a field instrument. He had not intended to imply that the loss of a radioactive source was in itself a serious matter, but that if it fell into the wrong hands there might be serious consequences for others and it could not simply be written off. People were sensitive to novel forms of danger, especially from radioactivity. For instance, more dismay appeared to have been caused by the Windscale incident, in which no lives were lost, than by a recent fire in a Glasgow warehouse where 19 firemen were killed.

Mr. J. A'C. Bergne said he happened to know the Mabfen valley in Rhodesia well. His interest had been that the stream had been extensively worked for tin in the past and he had been looking for the spots where the concentrates had been recleaned in the hope of finding other valuable minerals in the discards. The first paper quoted a group of samples taken along the course of that stream; there was no mention of finding old workings and he would ask the authors how they had fared when taking their samples.

The other point was that no one had paid tribute to the fact that, until recently, it was entirely due to the wonderful sense of sight and touch of the native African that the bulk of the beryl was won in that continent. Also there seemed to be an element of 'recognition of shape' in that achievement though the European was unable to perceive the rudimentary crystal form or cleavage. It was interesting to note that no one had yet succeeded in producing an automatic picker of equal delicacy.

Mr. S. H. U. Bowie replied, on behalf of the authors of the second paper, to a number of the more important questions raised and said they would be dealt with more fully in a later written reply.

The President regretted that there was not time enough for more oral contributions but invited further comments in writing. He was sure all would agree that it had been a most enjoyable and instructive evening, and that the authors certainly deserved a full measure of thanks, not only for their remarks but also for displaying some of the apparatus and equipment used in connexion with the exploration for beryllium ores.

WRITTEN CONTRIBUTION

Mr. K. C. Branscombe: The gamma neutron electronic instruments for detecting and assaying beryllium ores, described in the paper by Mr. Bowie and his colleagues, were introduced by two of the authors to the United Kingdom Atomic Energy Authority's Geological Office in Salisbury, Southern Rhodesia, during 1959. Since then these instruments have been given full operational use in a programme of assessment of beryllium-bearing deposits. This work, and further tests of comparison with conventional methods of sampling and assaying, substantiate the findings reported by the authors, and the year's work has led to only minor modifications to the methods of operation they suggested.

The geological investigation is now fully dependent on these electronic instruments which have very considerably reduced the costs and time involved. For example, over 10 000 individual samples have been assayed on one unit in one year, and with shift work by the three African operators assays were undertaken at a rate of 1600 a month during peak periods. Assay results have been available to field staff a few days after sample collection, for an assay cost of about 1s. per sample. The alternative to this was conventional chemical assaying involving several qualified chemists, for which commercial assayers would charge up to five guineas per sample.

The development of the portable instrument has now considerably reduced the number of samples that need to be taken. The detailed assessment of grades of the surface parts of a large sized pegmatite (1000–2000 ft in outcrop strike length) and of its derived eluvial spread used to require approximately 2000 channel samples of 100 lb weight, taken from systematic trenches, which involved a team of 40 Africans and 2 Europeans for two months. Equivalent results can now be obtained with the use of a portable instrument by one European and 10–20 Africans within a month, with only 20 or so samples being taken for laboratory assay. Furthermore, in the initial examination of all the known beryllium pegmatites, undertaken to provide a quick appreciation of their relative importance, the deductions based on mineralogy can now be amplified with an approximate figure for beryllium grade, rapidly obtained with the portable instrument.

It has been found that geologists introduced to the field instrument for the first time do not readily place full confidence in the results obtained. This is due to the considerable variations in readings that may be obtained both successively at the same station and from moving the instrument only a few inches from one station to another. These variations arise from normal statistical variation in the random counts, and from rapid fall-off of sensitivity of the instrument with distance from the centrally-placed gamma source, the effect of which is most pronounced on coarse-grained inhomogeneous material typical of most pegmatites. In fact, of course, little weight should be given to the results from any *one* station, and the use of the instrument for determining beryllium grade of a deposit essentially depends upon the averaging of a large number of readings, and this fundamental principle must be understood by all users of the instrument. When deposits have been assessed by both instrumental and conventional methods, the close agreement of results has led to full confidence in the instrument.

This close agreement may be shown by the following example of results obtained for two chosen areas of eluvium from a comparatively fine-grained pegmatite, in which the beryl grain size is predominantly about ¼ in. in diameter.

	Area A (100 ft by 100 ft)		*Area B (100 ft by 60 ft)*	
	No. of samples or readings	*% BeO*	*No. of samples or readings*	*% BeO*
(1) Deduced from previous laboratory assay of conventional sampling in adjacent trenches	20	0·046	40	0·092
(2) Laboratory assay of conventional channel sampling in pits in areas . . .	16	0·047	8	0·098
(3) Field instrument assay (in containers) on the same channel samples as (2) above	64	0·054	32	0·074
(4) Field instrument assay (in containers) on complete spoil from same pits . . .	640	0·055	320	0·099
(5) Field instrument on surface .	441	0·043	77	0·097

The agreement becomes less precise as the mineral grain size and hence relative inhomogeneity increases, which can be countered by increasing the number or closeness of the instrument readings. For accurate work when the grain size is of the order of several inches it is necessary to take a series of adjacent readings so that the whole rock face is covered by successive positions of the instrument. When this is done the instrumental results agree closely both with laboratory assays and with visual counts of crystal areas.

As discussed by the authors, the differences in relief and type of material under investigation by the instrument are allowed for by the use of a conversion factor, which is quoted in terms of source strength and BeO grade. While it should be theoretically possible to obviate the need to know source strength by using a calibration standard of known grade in the field, this has not been found possible, as geometry and physical characteristics of a standard cannot easily be made the same as the conditions encountered in natural beryllium deposits.

Further extensive work on the determination of conversion factors for a variety of material has produced results similar to those quoted in the paper. In contradiction of the authors, however, it has been shown necessary in certain circumstances to undertake field assays with the instrument on samples placed in containers, rather than to rely entirely on readings *in situ*. The field assays are undertaken rather than readings *in situ* on eluvium exposed in the vertical section in trenches, for which there is considerable difficulty in maintaining good contacts between the material and the instrument, without involving the operators in considerable doses of gamma radiation. It has been found that the human error, quoted by the authors, is much less in sample collection from channels which can be inspected, than in taking readings with the instrument in the sides of trenches. The field assay in a container is necessary for augered samples as for example from waste tailings dumps. Naturally readings *in situ* are made whenever possible. The comparison given in the paper of field assays in containers and of laboratory assays are based on tests using a container 10½ in. square. With the use of a container 18 in. square, on which four instrument readings can be made, closer agreement has been obtained between field and laboratory assays both of individual results and for the average grade of deposits.

It must be emphasized that the sensitivity of the instrument depends particularly on the number of counts recorded. For the purposes of rapid assessment of approximate grades of deposits, as opposed to the detailed assessment of defined zones in selected deposits, the counting time is normally 1 minute. The aircraft companies impose a limit of source strength for the shipment of isotopes in wingtips, so that the source strength of isotopes reaching field parties in Rhodesia is rarely above 70 mc, and for economy the sources are used down to a strength of about 25 mc. The neutron background in Rhodesia, with altitudes of about 4000 ft above sea level, is about 5 counts/min. For a 30-mc source, material containing about 0·03 per cent BeO (a grade commonly encountered) would give about 9 net counts/min. Statistically, two-thirds of all counts taken at the one station would be between 0·013 per cent and 0·047 per cent BeO; that is, the standard deviation would be more than 100 per cent of the mean. Thus, for accuracy, sufficient counting time is of prime importance, but for rapid work the inaccuracies would tend to cancel out, and a 1-min count is sufficient.

The potential danger of the isotopes has been appreciated by the African operators, without their showing reluctance to handle the instrument. Doses of radiation, recorded for each operator by dosimeters and film badges, have been well below tolerance level. However, the fact that the instrument uses a lethal isotope should never be forgotten, and for this reason the instrument should not be used without supervision by responsible persons with an understanding of isotope operation. This should not of course deter mining companies from making use of these laboratory and field instruments which have been shown by a year's operational use to be an almost indispensable tool for the large-scale investigation of beryllium ore deposits.

Some Geochemical Anomalies in Soil and Stream Sediment Related to Beryl Pegmatites in Rhodesia and Uganda

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Some Geochemical Anomalies in Soil and Stream Sediment Related to Beryl Pegmatites in Rhodesia and Uganda*

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550.84:553.679(676.1+689.1)

SYNOPSIS

Using a rapid colorimetric test, beryllium anomalies up to 600 ft wide were detected in the near-surface horizon of residual soils overlying beryl pegmatites at several localities in Rhodesia and Uganda. Peak values are commonly 10–20 ppm Be, rising sharply to 80–125 ppm immediately over the principal beryl zones, as compared to the background contents of 0·5–4 ppm Be in normal soils derived from barren country rock. Similar, though more erratic patterns of higher values, are detected by using a field beryllium monitor. Spectrographic analysis has shown that the soil over one dyke also contains anomalous contents of Li, Rb, Ba, Sr and Sn. In general, these elements all show anomalies comparable in width to that given by Be.

Stream sediment anomalies are also developed in those areas where the soil anomaly is being actively eroded, and in one area values of 4–10 ppm Be compared to the local background of 1 ppm were found to extend for at least 3500 ft downstream from a previously unsuspected pegmatite deposit.

ONE OF THE PRINCIPAL PROBLEMS in prospecting for beryllium arises from the close physical resemblance between beryllium minerals and some of the common rock-forming gangue minerals with which they may be associated. Moreover, until recently there has been no simple chemical or other test that could be used as a means of identification. This fact in part explains why little attention has been paid to the possible application of geochemical methods in the search for beryllium ores.

In 1958, however, the Geochemical Prospecting Research Centre at Imperial College was invited by the U.K. Atomic Energy Authority to undertake a study of this problem in beryllium pegmatite areas in Rhodesia and Uganda. This project forms part of a co-ordinated programme which includes research and development work on geochemical and instrumental (gamma-neutron beryllium monitor) techniques undertaken by the National Chemical Laboratory, the Atomic Energy Research Establishment at Harwell and the Atomic Energy Division of the Geological Survey of Great Britain. Although the geochemical study is not yet complete, the interim findings permit certain empirical conclusions to be drawn, which are

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presented here to complement the results of the chemical and beryllium monitor investigations given in separate, complementary communications.[1,2]

Previous Work

Although the literature on the occurrence and fundamental geochemistry of beryllium is fairly extensive,[3–5] very little has been published that is directly relevant to prospecting.

Primary dispersion of beryllium is considered to have taken place in the wall-rocks of pegmatites in New England, U.S.A.[6] The maximum beryllium content determined was 20 ppm. The probable width of the dispersion is not given.

Experimental soil samples collected over a beryl-columbite pegmatite in Uganda (J. S. Webb, unpublished data, 1954) show peak values up to 300 ppm in the residual overburden directly over the dyke; samples of colluvium along a base of slope traverse 200–300 ft below the sub-outcrop contain 50–100 ppm Be against a background of < 3 ppm. Over another dyke, erratic distribution of beryllium up to 40 ppm was recorded. These results were obtained on near-surface soil samples where the overburden ranged from 2–6 ft thick.

Both plant and soil sampling have disclosed beryllium anomalies related to beryl pegmatites in Russia.[7,8] Here, peak metal contents have been reported ranging up to 40 ppm Be in plant ash and 20 ppm in soils as compared to background concentrations of < 3 ppm. The maximum depths of the residual overburden in these areas ranged from 4–12 ft. In one area, anomalous concentrations of Be in the soil extend up to 60 ft from the pegmatite sub-outcrop where the cover does not exceed 6 ft thick. In another area, Be is dispersed in the soil for only a few feet on either side of the dyke, while lithium gives a somewhat wider anomaly and is considered to be a better indicator element.

Samples of the active sediment from rivers draining stanniferous granites in Malaya contain up to 40 ppm Be in the minus 80-mesh fraction as compared to the normal background content of < 3 ppm (J. S. Webb, unpublished report to Geological Survey of Malaya, 1958). These results, which are being followed up by detailed studies, show a degree of positive correlation between the concentrations of Be and Sn. The nature of the beryllium source is not yet known.

ANALYTICAL TECHNIQUES

In the aforementioned previous work and also in the initial stages of the present study, the beryllium content was determined spectrographically. The spectrographic analyses quoted in this paper were carried out by the writers' colleague, J. D. Kerbyson, using both anode and cathode arc techniques with lithium carbonate buffer. Most of the data, however, were obtained in the field using provisional colorimetric procedures which

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[1]etc. See list of references at the end of the paper.

included a titration method devised by A. H. Debnam and a buffer technique originated by our colleague, R. E. Stanton, both of these tests being based on the analytical approach used by the National Chemical Laboratory at a time when their final field procedure was in an early stage of development. The latter procedure and the buffer technique are described in a joint paper by Hunt, Stanton and Wells.[1] Details of Debnam's titration method are given in the addendum to the present paper.

For purposes of comparison, beryllium monitor assays were kindly undertaken in the field and laboratory by K. C. Burke* and Miss M. Green† respectively. The methods and equipment employed are described by Bowie *et al.*[2]

Unless stated otherwise, all analyses given in this report were carried out on the minus 80-mesh (BSS) fraction of the air-dried sample; 50- to 100-g samples of soil or stream sediment are usually sufficient to provide enough minus 80-mesh material for analysis. The minus 80-mesh fraction was provisionally chosen for the field work following preliminary sizing tests which showed a fairly even distribution of beryllium in all size fractions from minus 20- to minus 200-mesh. These tests were carried out on samples from the initial trial area and it does not necessarily follow that minus 80-mesh is the optimum fraction for samples from other areas.

Comparison of the various laboratory techniques.—The results obtained on selected samples by chemical, spectrographic and laboratory beryllium monitor tests are given in Table I. Despite evident bias, each of the

TABLE I.—*Beryllium Values obtained by Various Laboratory Techniques, in ppm*

Sample no.	Laboratory beryllium monitor‡	Spectrography	Colorimetry		
			Titration	Buffer	N.C.L.
206275	1	5	0·4	< 0·5	0·5
76	3	8	1	1	0·5
77	20	35	16	9	12
78	45	55	35	25	19
79	35	45	30	19	25
80	90	100	90	60	65
81	100	105	110	65	70
82	70	80	90	60	60
83	25	25	25	18	25
84	17	25	25	13	17
85	13	16	20	10	15
86	10	8	13	8	8
Mean Reproducibility[10]	—	± 50%	± 20%	± 30%	± 30%

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*Atomic Energy Division, Geological Survey of Great Britain.

†United Kingdom Atomic Energy Authority.

‡Beryllium monitor analyses by U.K.A.E.A., Salisbury. All other analyses carried out at the Geochemical Prospecting Research Centre.

methods has proved itself capable of detecting anomalies with an acceptable degree of reproducibility.

Of the colorimetric procedures, only the provisional titration and buffer techniques have been tested under field conditions. These tests, which have involved several thousand determinations, have shown that it is possible to carry out about 40 samples per 8-hour man-day using the titration method as compared to 60 samples per day by the more simple buffer technique. The simplicity of the latter also favours it as a routine field method. Both tests operate satisfactorily in the range 1–600 ppm Be; higher values may be determined by diluting the extracts. The limiting sensitivity is 0·1 ppm by titration as compared to 0·5 ppm by the buffer reaction. The titration method gives the best discrimination in the range 0·1–10 ppm but, where a coarser discrimination can be tolerated, the buffer method is preferable because of the greater productivity and simplicity which make it more suitable for routine work. Preliminary tests indicate that the National Chemical Laboratory's procedure[1] has performance characteristics similar to the buffer method.

The field beryllium monitor has a limiting sensitivity of 2 ppm Be but, with the instrument in its present stage of development, the practical working limit is about 5 ppm (S. H. U. Bowie, personal communication).

GEOCHEMICAL RESULTS

Preliminary sampling was carried out in the vicinity of a number of pegmatite occurrences in Rhodesia with assistance from members of the staff of the U.K. Atomic Energy Authority. Spectrographic analysis showed that beryllium anomalies with peak values of 10–80 ppm were invariably detected in residual overburden derived from beryl pegmatites of marginal or economic grade, i.e. *c.* 0·05 per cent BeO. A feeble anomaly was also disclosed by sampling over a deposit of fine-grained beryl disseminated in schist country rock, but only negative results were obtained over small sub-economic dykes. In some areas there was evidence of anomalous values in the local drainage, but these could have been due to contamination. For both soils and stream sediments, background values range from less than 3 ppm in the case of schist bedrock to 6–10 ppm* in the case of granite.

The results of this work were followed up by detailed studies in selected areas. In addition, geochemical sampling was also undertaken in southwest Uganda, where conditions were more suitable for a study of metal dispersion in the surface drainage system. The location of the field areas is shown in Fig. 1.

A total of 7000 samples has been collected during the work to date, but only a small representative selection of the data is given below. A more detailed account will be prepared when current laboratory examinations are completed.

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*Preliminary spectrographic data; values probably high.

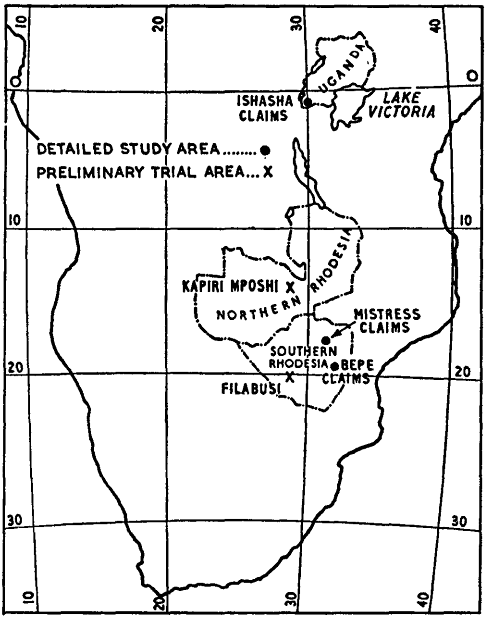

Fig. 1.—Beryl pegmatite study areas in Rhodesia and Uganda.

Bepe Claims, Buhera District, Southern Rhodesia

The Bepe No. 2 pegmatite ranges up to 250 ft wide over a length of 700 ft and forms a minor topographical feature in a generally flat terrain. The residual overburden, which varies from a few inches to 8 ft thick, is a degraded latosol and supports a thin sub-tropical forest vegetation.

The complex quartz-felspar-mica pegmatite is well zoned and carries beryl in crystals up to 12 in. and more in diameter, which appear to be associated with narrow quartz bands or lenses. Country rock is tremolite schist.

Soil sampling.—The study area was confined to the eastern end of the dyke, which is essentially undisturbed by mining activity in contrast to the western end which lies within another group of claims where it has been worked by opencasting.

Typical geochemical traverses are illustrated in Figs. 2 and 3. The results of colorimetric and spectrographic analyses demonstrate the existence of broad, near-surface soil anomalies which rise to peak values of 30–80 ppm Be as compared to the background of 0·5–1·5 ppm for soils derived from the schist country rock. On both traverses, the anomaly peaks reflect the main beryl zone.

There is evidence of lateral dispersion of beryl in the soil for distances up to 150 ft on either side of the dyke. The dispersed metal is undoubtedly derived from the dyke as samples of the host rock collected more than 5 ft from the contact gave no more than background values.

Samples collected from different depths indicate that values in the minus 80-mesh fraction of the soil remain essentially constant throughout the profile, although in some places there are indications of a tendency for Be to be enriched slightly in the organic topsoil.

An interesting feature of the results is the general regularity and homogeneity of the values across the full width of the dyke, interrupted only by the anomaly peak over the main beryl zone, despite the apparently irregular distribution of beryl in the zoned pegmatite bedrock. The distribution of beryllium in the fine soil fraction does not appear to be affected by the erratic distribution of occasional coarse fragments of beryl scattered through the overburden. Beryl is usually considered to be relatively

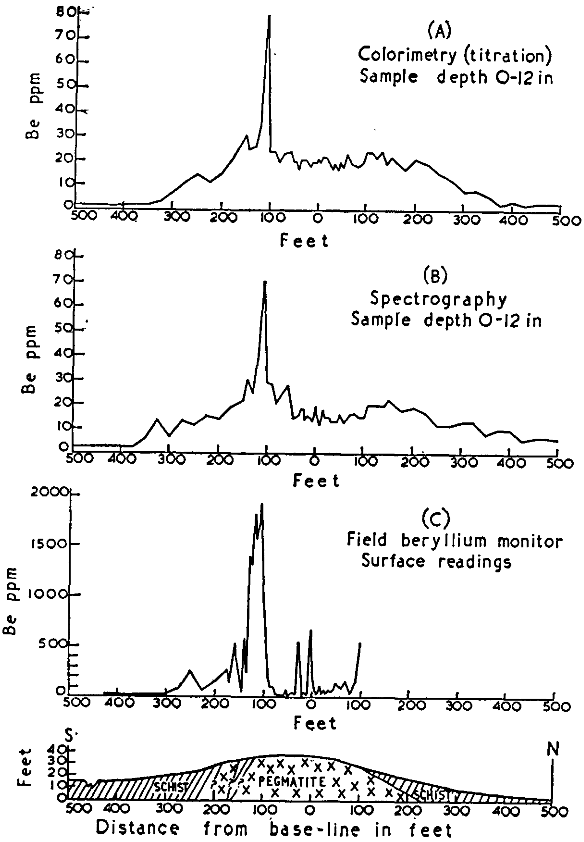

Fig. 2.—Soil anomalies related to beryl pegmatite. Traverse 150W Bepe No. 2 Claim, Southern Rhodesia. (Field beryllium monitor readings by K. C. Burke; spectrographic analyses by J. D. Kerbyson.)

resistant in the zone of weathering and it seems unlikely that all the beryllium in the minus 80-mesh fraction of the soil is due to fine particles of this mineral. Further work is being done to determine to what extent the apparent homogeneity of the values is due (*a*) to beryllium derived from the weathering of the associated pegmatite minerals, and (*b*) to chemical or biochemical dispersion. In this connexion, Beus[4] is of the opinion that 25–50 per cent of the total Be in beryl pegmatites may be incorporated in felspar (up to 200 ppm Be) and in mica (90 ppm Be). He also considers that the Be content of these minerals need not be an indication of the beryl content of a pegmatite. If this conclusion is generally valid, it will naturally have an important bearing on the interpretation of geochemical soil survey data. The possibility of chemical and biochemical

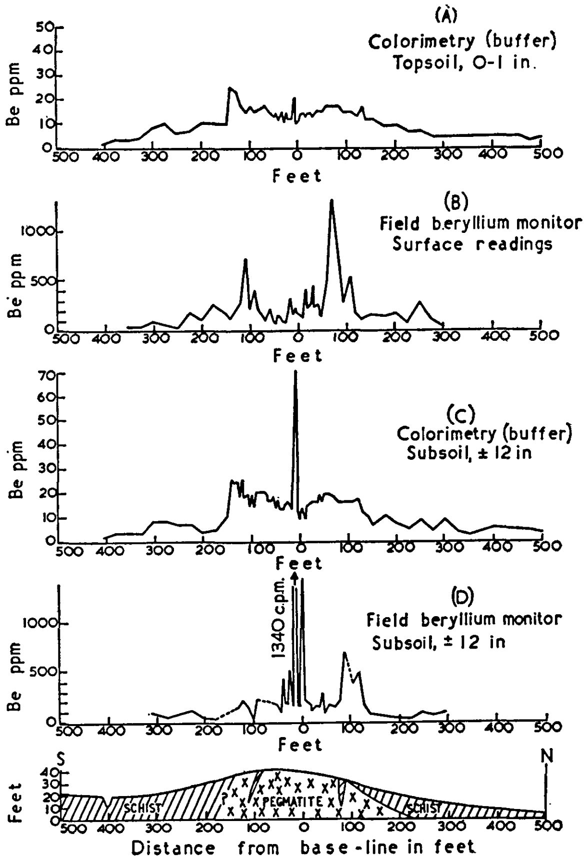

Fig. 3.—Soil anomalies related to beryl pegmatite. Traverse 250W Bepe No. 2 Claim, Southern Rhodesia. (Field beryllium monitor readings by K. C. Burke.)

dispersion has already been demonstrated by the work of Zalashkova *et al.*[7]

For purposes of comparison, K. C. Burke carried out a trial field beryllium monitor survey along the soil traverses illustrated in Figs. 2 and 3. Both methods give broadly similar anomalies with peak values over the main beryl zone. The instrument readings also show a number of other anomaly peaks which do not always coincide with the peaks detected at a different depth along the same line of traverse (Figs. 3B and 3D). The generally higher level of values and the more erratic metal distribution detected by the beryllometer probably reflect the additional beryllium contents of the coarser soil fractions and the presence of scattered beryl fragments, neither of which contribute to the chemical results obtained in the minus 80-mesh fraction.

Soil samples from the traverse illustrated in Fig. 2 have also been analysed spectrographically for a number of other metals. The principal features of the results, which are given in detail in a separate report by Kerbyson and Webb,[9] are summarized below:

(*a*) Be, Li, Rb, Ba, Sr and Sn show positive anomalies related to the pegmatite.

(*b*) Ni, Co, Cr, V and Cu show 'negative' anomalies, or troughs over the dyke. The higher values on either side are almost certainly related to the basic nature of the schist country rock.

(*c*) Mn, Pb and Ga show little tendency to vary in a manner that can be related to the geology, although there is, perhaps, slight evidence that Mn decreases over the dyke, as might be expected.

(*d*) There is little difference in the contrast between anomalous and background values for Li and Be (cf. Karaeva and Chesnokov[8]). The contrast for Rb is rather greater, however, while that for Ba, Sr and Sn is distinctly less. In general terms all the anomalies have comparable widths.

Stream sediment sampling.—In addition to the soil traverses, stream sediment samples were also collected from the surface drainage in the vicinity of the dyke. Only background values of 1–3 ppm were detected in uncontaminated streams, even in a tributary which passes within 300 ft of the dyke; the soil anomaly does not extend to the banks of this stream, however. Anomalous values up to 12 ppm Be noted for 1500 ft downstream from the workings are suspect because of the possibility of contamination.

A stream passing within 1000 ft of another mineralized dyke (Bepe No. 4) also gave background values, rising to 3–5 ppm Be 2000 ft downstream where the drainage passes from tremolite schist on to granite gneiss which is cut by numerous small pegmatite dykelets. The soil anomaly associated with this dyke is similar in width to that recorded at Bepe No. 2 although the peak values do not exceed 25 ppm Be.

Mistress Claims, Salisbury District, Southern Rhodesia

The Mistress Claims are situated on a pegmatite dyke system which may extend for some miles along strike. On the section where sampling was carried out the dyke is 150 ft wide and coincides with the crest of a prominent ridge. The country rock is mostly gneissic granite with some schist. The residual overburden varies from 0 to 6 ft thick, although over most of the area investigated the cover does not exceed 1–2 ft. The thin forest vegetation is more sparse than at Bepe.

The pegmatite is complex and microlite and some beryl, lepidolite and spodumene are being recovered from opencast workings.

Soil sampling.—In order to avoid contamination, geochemical sampling was confined to the northwestern end of the Claims where no mining activity has yet taken place.

Along a typical traverse (Fig. 4) the anomalies obtained by analysing

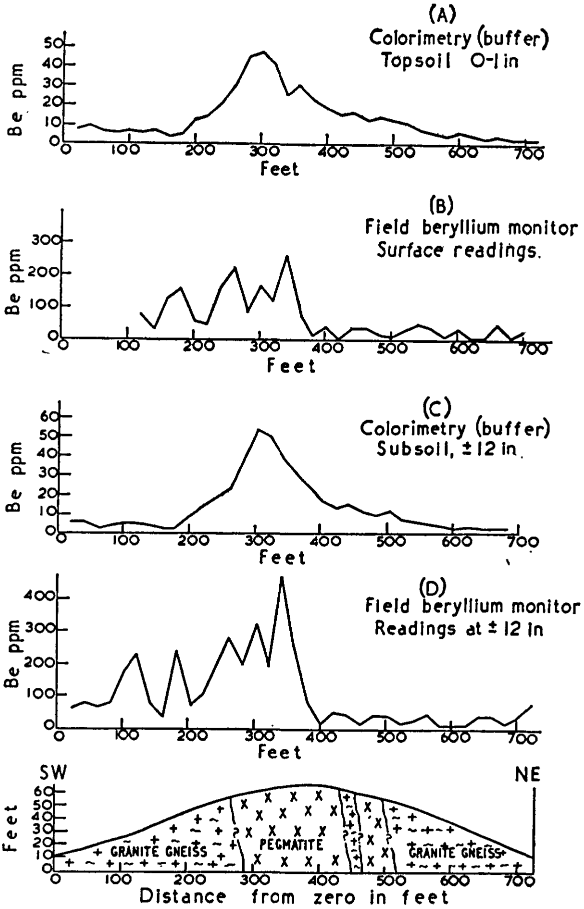

Fig. 4.—Soil anomalies related to beryl pegmatite. Traverse MN, Mistress Claims, Southern Rhodesia. (Field beryllium monitor readings by K. C. Burke.)

both the topsoil and the subsoil are comparable and homogeneous over a width of 400 ft with peak values rising to 50 ppm Be. These values compare with the local background of 1–2 ppm for gneissic granite and 2–3 ppm for schist.

The corresponding beryllium monitor results, which are also given in Fig. 4, show the same features as were evident in the Bepe area.

Sediment sampling.—The results of stream sampling are shown in Fig. 5. The local background is 1·0–1·5 ppm Be. It is difficult to estimate the extent to which opencast operations may have contributed to the drainage train in the Mabfeni River. In the western tributary draining the Mistress Claims there is essentially no contamination and here anomalous Be values decrease from 7·5 to 3·0 ppm over a distance of 2000 ft to the confluence with a contaminated tributary near the mainstream.

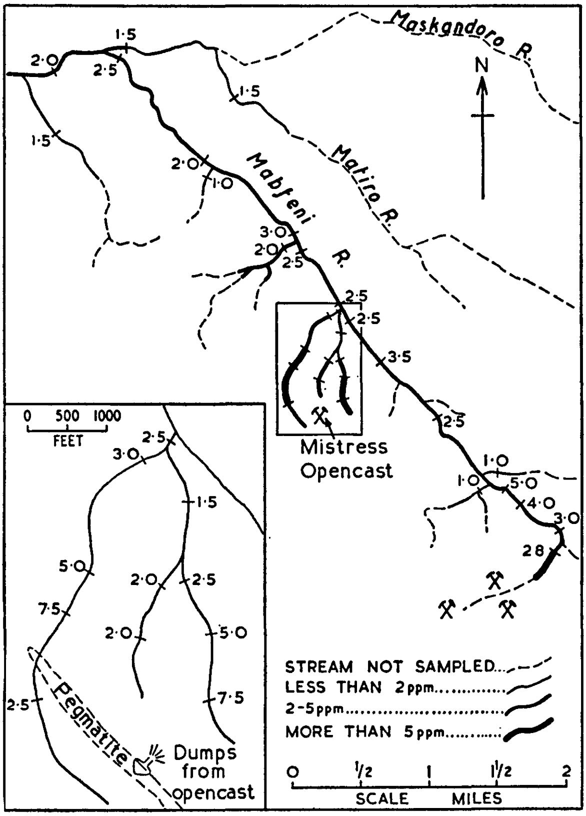

Fig. 5.—Distribution of beryllium in stream sediment, Mistress area, Southern Rhodesia.

Kapiri Mposhi Area, Northern Rhodesia

In this area a small pegmatite dyke, up to 6 ft wide, occurs in granite gneiss country rock. The dyke, which contains a little coarse-grained beryl, lies on moderately inclined, freely drained ground near the edge of a narrow seasonal swamp, or dambo. Apart from the dambo grassland, the vegetation is thin forest.

An erratic, poorly defined soil anomaly with values of 15 ppm Be was detected over a width of about 120 ft in freely drained soil and extends asymmetrically downslope from the sub-outcrop. Anomalous values up to 40 ppm Be occur in the organic-rich topsoil of the dambo profile near the dyke. Both updrainage and downdrainage, the beryllium content of the dambo soil varies widely from < 3 to 15 ppm. The higher values may well be due to other pegmatites scattered throughout the area, since pegmatite debris was found in the sub-surface gravel horizon at a number of places along the drainage.

Ishasha Claims, Kigezi District, South West Uganda

In contrast to the Rhodesian areas, the Ishasha Claims lie in rugged dissected country covered by dense tropical forest. Apart from the fact that zoned complex beryl pegmatites of variable width occur in mica schist, little is known of the geology, which is concealed beneath persistent residual soil up to several feet thick in places. Moreover, at the base of slopes it is common to find 10 ft or more of colluvium derived from the higher ground.

Soil sampling.—Although a fairly extensive programme of contour soil sampling has been undertaken around the opencast, only a few samples have yet been analysed. However, anomalous values ranging up to 125 ppm have been detected in the residual overburden on the steep slopes. Base-of-slope sampling in the valley colluvium could not be tested on account of mining activity on the upper slopes. It is probable, however, that anomalies exist in the colluvium similar to those previously detected downslope from another pegmatite in Uganda (p. 330).

Stream sediment sampling.—The results of stream sediment sampling in the drainage system around the Ishasha claims are shown in Fig. 6.

The anomalous train of values which extends from the workings for 7000 ft to the confluence with the Ishasha River is suspect in view of the possibility of contamination arising from mining activity.

Preliminary samples collected upstream, where the drainage is uncontaminated, disclosed anomalous values of 4–9 ppm Be as compared to the background of 1 ppm. These anomalous values were traced for 3500 ft to a tributary where the beryllium content of the sediment rose to 15 ppm. Upstream, the values dropped rapidly to background. The source of the sediment anomaly was found to be a pegmatite dyke approximately 100 ft wide which crosses the stream at the anomaly 'cut-off'. Bank samples at this point contain 20 ppm Be and soil traverses along the steep slopes on

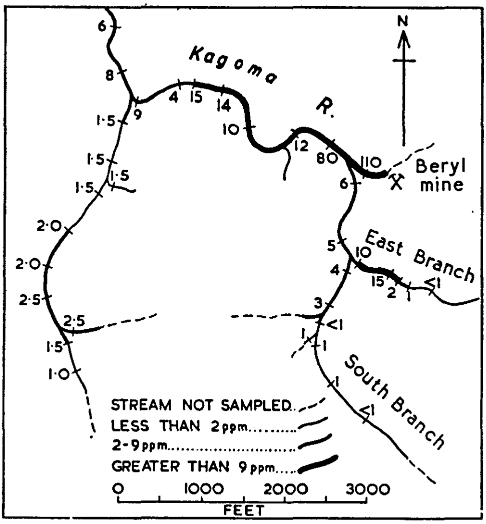

Fig. 6.—Distribution of beryllium in stream sediment in the Ishasha area, S.W. Uganda. (The anomalous drainage train as indicated on the plan appears shorter than is in fact the case because of the very irregular course followed by the stream which cannot be illustrated in detail at this scale.)

either side of the stream showed an anomaly ranging up to 80 ppm. The grade of this dyke, the presence of which was previously unsuspected, is not known.

SUMMARY AND CONCLUSIONS

1. With the aid of rapid colorimetric tests for beryllium, geochemical soil anomalies were detected over several beryl pegmatites examined in Rhodesia and Uganda.
2. Anomalies in the residual overburden may spread up to 150 ft or more beyond the contacts of the pegmatite. Peak metal concentrations rise to 10–125 ppm Be as compared to the background content of 0·5–4 ppm in normal soils derived from the country rocks.
3. Although the largest anomalies were related to the more promising deposits and only feeble or negative results were obtained over small sub-economic pegmatites, it is not certain to what extent the size of a soil anomaly can be related to the economic potential of the parent pegmatite.
4. There is evidence that zoning or other primary segregation of beryllium within the dyke may be reflected in the metal content of the immediately overlying soil.
5. Apart from local peaks related to beryl zones, the anomalies show a remarkable degree of regularity and homogeneity in contrast to the apparently irregular distribution of beryl in the underlying pegmatite. The essentially even distribution of beryllium in the minus 80-mesh fraction at all depths in the soil may be due in part to beryllium derived

from pegmatite minerals other than beryl coupled, perhaps, with chemical and biochemical homogenization during weathering and soil formation.

6. Beryllium anomalies are also detected in stream sediments and dambo (seasonal swamp) alluvium when the local surface drainage is actively eroding anomalous soil. In one such case, a drainage train was traced for 3500 ft to disclose a previously unsuspected beryl-bearing pegmatite which crossed a stream at a point where the active sediment carried 15 ppm Be as compared to the local background of 1 ppm or less. Peak values in the associated soil anomaly on the adjoining slopes were 80 ppm Be. The grade of the deposit is not known.

7. Independent field beryllium monitor surveys carried out over three soil traverses confirm the existence of the anomalies. The beryllium monitor shows a much more erratic pattern of generally higher values. These differences are considered to be due to the fact that the instrument responds to the beryllium content of the total soil, including any coarse beryl fragments that may be present, while the chemical data record the content of the fine soil fraction only.

8. Li, Rb, Ba, Sr and Sn also show positive soil anomalies, comparable in width to that of Be. Li and Be give a similar anomaly contrast exceeded only by Rb. Both Li and Rb are more mobile than Be and may be dispersed more effectively in the surface drainage.

General Conclusions

Though admittedly incomplete, the results of these preliminary studies indicate that geochemical methods can undoubtedly assist in exploration for beryllium ores concealed beneath residual overburden. In this connexion it is important to stress that the field beryllium monitor is as much a geochemical tool as is chemical analysis of soil and stream sediment samples.

It is perhaps early to comment in detail on the possible scope of these methods which are still in their infancy. However, in general terms, it seems probable that the field beryllium monitor is better suited to prospect appraisal, i.e. discrimination of barren and mineralized deposits, location of metal concentrations in known deposits and the tracing of their extensions. In prospecting virgin country, either method may be preferable as a means of locating concealed deposits depending on the size and tenor of the soil anomalies developed. When there is an adequate drainage pattern, however, it is possible that stream sediment sampling could be used to good purpose as a primary reconnaissance method to delimit focal points for more detailed prospecting. The application of the field beryllium monitor in reconnaissance has yet to be investigated. In addition the chemical methods of analysis have still to be tested on soils and sediments derived from concentrations of beryllium minerals other than beryl.

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ADDENDUM

Beryllium Estimation by the Titration Method

by A. H. DEBNAM

Procedure

1. Dispense 4 g of ammonium fluoride into a silica crucible.
   Use a calibrated dispenser made from glass tubing with a plunger.
   Operate with a batch of samples sufficient for the day's work (50–60).
2. Weigh 1 g of sieved sample and mix with the ammonium fluoride.
3. Heat the mixture vigorously over a burner for 5 min, break up the residue with a spatula and continue heating for a further 3 min, when fuming should cease and the residue will be at red heat. Continue heating for another 2 min and then allow the crucible to cool on an asbestos mat.
   Four crucibles fit on a primus stove and two stoves can be operated concurrently. If the heating operation takes more than 12 min an improved source of heat should be used.
4. Add 10 ml of 0·2N-nitric acid, heat to boiling, stir with glass rod and immediately add another 10 ml of 0·2N-nitric acid. Mix and allow to stand for 1 hour.
   Deliver the acid by means of an automatic dispenser.
5. Pipette an aliquot (up to 10 ml) of the clear solution into a test-tube and make the volume up to 10 ml with 0·2N-nitric acid.
   Operate with batches of 10 or 12 samples from this stage. Use a 2-ml or 5-ml automatic pipette for large aliquots, and a 1-ml graduated pipette for small aliquots. 19 by 160-mm test-tubes should be calibrated at 10 ml. The acid is added from a polythene wash bottle.
6. Add 1 ml of Nervanaid F solution.
   Use an automatic pipette.
7. Add 2 ml of sequestric acid solution.
   Use an automatic pipette.
8. Add 1·1 ml of 10 per cent sodium hydroxide solution and mix by inverting the tube.
   Use an automatic pipette. The exact amount of 10 per cent sodium hydroxide must be determined by experiment. Prepare a 3·5 μg standard by the present procedure. If at step 10 the solution is blue the correct volume of sodium hydroxide has been dispensed. If the colour of the solution has a red component proceed to step 11 where if more than four drops of 2 per cent sodium hydroxide are required to remove the red component it will be advisable to increase the amount of 10 per cent sodium hydroxide added at step 8. However if the red component is not removed at step 11 the volume of 10 per cent sodium hydroxide must be reduced. Test a fresh 3·5 μg standard after making each adjustment, until the maximum blue colour is achieved at step 10.
9. Add 1 ml of 0·025 per cent beryllon II solution and invert tube to mix. Allow to stand at least 5 min.
   Use an automatic pipette.
10. If the solution is blue, violet, or red-voilet compare with a standard series and note the value. Then titrate dropwise with 2 per cent sodium hydroxide until the blue component of the mixed colour reaches a maximum. Invert the stoppered tube to mix the solution after each addition of the reagent. Less than five drops of sodium hydroxide should be necessary. Compare with the standard series and note the final value which may be higher or lower than the first value recorded. The highest observed value represents the correct result. If the reading is greater than 3 μg repeat the test using a smaller aliquot of the test solution.
    Use a burette for the titration.

11. If the solution is red-pink with no blue component (compare with the 0·25 μg standard) titrate dropwise with 2 per cent sodium hydroxide until there is no further increase of the blue component. Compare with the standard series and note the value. Allow the solution to stand for 10 min before re-titrating dropwise with 2 per cent sodium hydroxide to the maximum blue component of the colour, at which point the final value is obtained. The second reading should be greater than the first.

    Use a burette for the titration. If the amount of 10 per cent sodium hydroxide added at step 8 is correct, only test solutions containing aliquots greater than 2 ml should require step 11, when the colour of the solution will return to red-pink between titrations. Even if no beryllium is present in the test solution, resulting in a complete absence of the blue component, it is possible to detect the end-point of the titrations in steps 10 and 11 by observing the intensity of the red-pink colours. An appreciable change from a weak red-pink to an intense red-pink (same as the 0 μg standard) will be observed at the end-point.

12. The beryllium content in parts per million (ppm) is obtained from the expression

$$\frac{s \times v}{w \times a}$$

where s = value of matching standard (μg)
v = volume of extraction solution (ml)
w = weight of sample (g)
a = aliquot of extraction solution (ml)

Preparation of Standards

To 12 test-tubes add respectively 0, 0·25, 0·5, 0·75, 1·0, 1·25, 1·5, 1·75, 2·0, 2·5, 3·0 and 3·5 ml of the standard solution containing 1 μg of beryllium per ml and continue as described in steps 5 to 10 of the above procedure.

Use a 5-ml graduated pipette. The zero standard should have a red-pink colour, while in the remainder the blue component should increase uniformly to a pure blue at 3·5 μg. Stoppered standards have been kept successfully for 3 weeks but in practice they are prepared daily.

Preparation of Reagents

0·2N-nitric acid:

Dilute 65 ml of the concentrated acid (sp. gr. 1·41) to 5 litres with demineralized water.

Nervanaid F solution:

Dilute 250 ml of 20 per cent Nervanaid F to 1 litre with demineralized water.

Sequestric acid solution:

Dissolve 100 g of sequestric acid (di-sodium salt of ethylene diamine-tetra-acetic acid) in 1600 ml of warm demineralized water and dilute to 2 litres.

Sodium hydroxide solution, 10 per cent:

Dissolve 100 g of sodium hydroxide pellets in 800 ml of demineralized water and dilute to 1 litre.

Sodium hydroxide solution, 2 per cent:

Dilute 200 ml of the 10 per cent solution to 1 litre with demineralized water.

Beryllon II solution, 0·025 per cent:

Dissolve 100 mg of beryllon II in 400 ml of demineralized water.